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TABLE OF CONTENTS

MARCH, 1917

JUNE, 1917

SEPTEMBER, 1917

DECEMBER, 1917

Terrestrial Magnetism
and
Atmospheric Electricity

Volume XXII MARCH, 1917 Number I

ON THE CONDUCTION OF ELECTRICITY THROUGH AN IONIZED GAS, MORE PARTICULARLY IN ITS RELATION TO BRONSON RESISTANCES.[1]

By W. F. G. Swann and S. J. Mauchly.

INTRODUCTION.

In many radioactive investigations in which the measurement of small currents is involved, the principle of allowing the current to enter an electrometer and escape through a standard high-resistance has been adopted, the deflection attained by the electrometer in the equilibrium state being the quantity which is directly measured, and which is proportional to the current sought, when the standard resistance obeys ohm's law. Bronson[2] has developed a convenient type of resistance in which the air between two parallel plates is rendered conducting by covering one of the plates with a layer of polonium. These resistances obey ohm's law over a considerable range, but their magnitude is such that for plates of 5 or 6 sq. cm. cross-sectional area they give currents of the order of magnitude of 10^{-2} E. S. U. for potential-differences of 3 volts. For some purposes very much higher resistances are required, as for example when the current to be measured is very small and the conditions are nevertheless such that it is undesirable to make the electrometer very sensitive.

The resistance may obviously be increased by increasing the distance between the plates or by reducing the intensity of the radioactive radiations, but such alterations are accompanied in general by a lowering of the potential range for which a linear relation between the current and the potential is obtained. Further, there is a practical limit to the reduction in the size of the electrodes, so that if the range of linearity is to be maintained for

[1] Presented at the meeting of the American Physical Society in Washington, April, 1916.
[2] Bronson, *Amer. Jour. Sci.*, vol. 19, p. 185, 1905.

radioactive cells of high resistance, it must be by an appeal to phenomena other than the more ordinary ones.

The present investigation was started primarily with the object of determining the conditions under which linearity could be most effectively attained, and of examining some of the points which influence the general behavior of radioactive resistances.

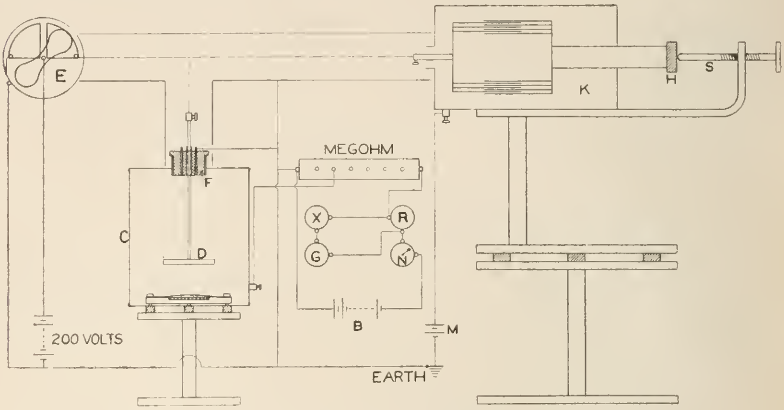

Fig. 1.—Diagram of the Experimental Arrangement.

General Nature of the Apparatus.

The currents through the ionization chambers were in all cases measured by allowing them to enter one of the quadrants of a Dolezalek electrometer, and balancing them by means of a condenser of adjustable capacity. One of the plate systems of the condenser was connected to the insulated quadrant, and the other plate system was connected to one pole of a battery of U volts (about 4 volts) potential, whose other pole was connected to the uninsulated quadrant. If the electrometer spot is kept at zero under these conditions, the current is given by $U\frac{\delta C}{\delta t}$, where $\frac{\delta C}{\delta t}$ is the rate of alteration of capacity of the condenser.

The apparatus is diagramatically illustrated in Fig. 1. K is the variable condenser, the variations in capacity being produced by the rotation of the screw S pressing on the insulating head H. The whole condenser is insulated, and its stand, which is in connection with one of the armatures, is connected to one pole of the battery M; the other pole of the battery is earthed. B is a battery of dry cells which causes a current to flow through the megohm, the standard small resistance R, and the variable resistance N in

series. R acts as a shunt on the portion of the circuit composed of the Galvanometer G and the resistance X, and by adjusting N so as to keep the deflection constant, the current through the megohm, and so the potential-differences between its individual tenths, may be kept constant in spite of possible variations in the battery. Various potentials could be applied to the outer case of the ionization chamber by tapping off from different points of the megohm; it is hardly necessary to describe the details of the measurement of these potentials. The insulating plug F supporting the electrode D was divided into two portions by a guard ring which was earthed, so that leakage from the outer case of C to the plate D was avoided. After a little practice it was easily possible to measure the currents with as much accuracy as was desired, the sensitivity of the arrangement being conveniently adjustable by altering the battery M.

NATURE OF THE RADIOACTIVE SUBSTANCE TO BE EMPLOYED IN THE CELL.

Where it is intended to use the radioactive resistance in circumstances in which constancy over a long period of time is desirable, a polonium deposit is of course not suitable, since its activity decays to half value in 136 days. The chief disadvantage associated with radium is the penetrating γ-ray radiation which it emits and which requires cutting out by plates of lead of a thickness comparable with 15 cm. in order to render its effects insignificant in the case of delicate work on the ionization of the atmosphere, for example. Ionium seemed, on the whole, to present the most promising features, although experiments were also made with radium and polonium, for the purpose of testing special points.

The chief disadvantage associated with ionium is the fact that it usually contains thorium, which gives rise to emanation. Even if the vessel is hermetically sealed the emanation may give rise to trouble, as may be seen from the following consideration: The successive decay-products of thorium are indicated by the following sequence, the half-periods being given in parenthesis:

a. Thorium (1.3×10^{10} years)
b. Mesothorium 1 (5.5 years)
c. Mesothorium 2 (6.2 hours)
d. Radio-thorium (2.0 years)
e. Thorium X (3.65 days)
f. Thorium *Em* (54 sec.)
g. Thorium A (0.14 sec.)
h. Thorium B (10.6 hours)
i. Thorium C_1 (60 min.)
j. Thorium C_2 (Very short) — Thorium D (3.1 min.)

All of these products, except Mesothorium 1 and 2, Thorium B, and Thorium D, give rise to α particles, and so, in the equilibrium-condition, the successive daughter products of thorium emanation emit 3 α-particles for every 4 α-particles emitted by the higher members of the series. In other words they contribute nearly as much to the ionization as the emanation and earlier products. Now, the emanation which is distributed throughout the air in the chamber gives rise to the successive products thorium A, B, C, etc., which, in the absence of the field diffuse to the walls. These products go on decaying and are continually replaced by fresh supplies. If, however, a field be applied, those portions of the fresh supplies which are formed throughout the volume of the vessel will be transferred to the negative electrode, since they are positively charged. As regards the very short-lived thorium A, the amount existing on the walls before the field was applied will disappear very rapidly on the application of the field, and the new distribution of the product, in which the thorium A is to be found entirely on the negative electrode, will be attained almost immediately. With the thorium B, however, the case is different; 10.6 hours after the application of the field half of the thorium B will have decayed from the walls, and the corresponding half, born since the application of the field, will be found on the negative electrode. The thorium C_1, thorium D, and thorium C_2 formed from the latter half will also be found on the negative electrode. Thorium B emits no α rays, but thorium C_1 and C_2 both emit α rays, and they are responsible for more than 25 per cent of the total ionization due to the thorium and its products. Hence in a period of about 10.6 hours, active material responsible for more than 12.5 per cent of the ionization will be transferred from one part of the vessel to another, with the consequence that the effectiveness of its ionization in determining the resistance of the cell will be completely altered. Such effects as these, extending over periods of several hours may readily impart erratic properties to a radioactive resistance, if the active substance emits an emanation and is not sealed off from the chamber.

In some of the experiments about to be described the active preparation was not sealed, but in others the ionium was spread over a shallow tray turned in the middle of a large disc of brass. The opening was covered with a piece of thin mica which was cemented to the brass so that the active preparation was completely shut off from the ionization chamber. The mica was covered with

two thicknesses of aluminum foil, which were held down by an aluminum ring screwed to the brass plate. The actual form of the radioactive cell varied in the different experiments to be described.

THE RELATION BETWEEN THE CURRENT AND THE POTENTIAL-DIFFERENCE BETWEEN THE ELECTRODES.

If the upper electrode, which in the present case was an aluminum disc 5 cm. in diameter, was close to the foil, a curve of the ordinary type was obtained showing a departure from linearity in

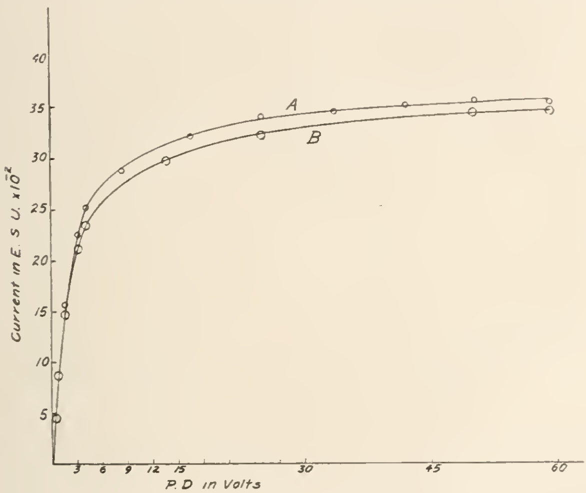

FIG. 2.—Current-Potential Curves with Electrodes 0.63 cm. apart.

a direction such as to indicate a less rapid variation of the current with potential than would be accounted for by a linear law. The curves for a distance of 0.63 cm. between the electrodes are shown in Fig. 2, *A* corresponding to a negative charge and *B* to a positive charge on the lower electrode. Both curves are of the ordinary familiar type and show a saturation current. The saturation current for the curve *A* is greater than that for *B*. This phenomenon has generally been observed in ionization chambers and has been attributed to a difference between the velocities of the positive and negative ions. It will appear from conclusions to be deduced later that another explanation seems more probable.

Curves *A*, *B*, *C*, *D*, Figure 3, correspond to distances respectively of 7, 7, 6, and 6 cm. between the plates. *A* and *C* correspond to positive, and *B* and *D* to negative potentials on the lower electrode.

It will be seen that, after showing an initial departure from linearity in the normal direction, the curves show a decided upward tendency. All of the curves shown in Fig. 3 were taken with the sealed specimen of ionium already referred to, and the ionization chamber

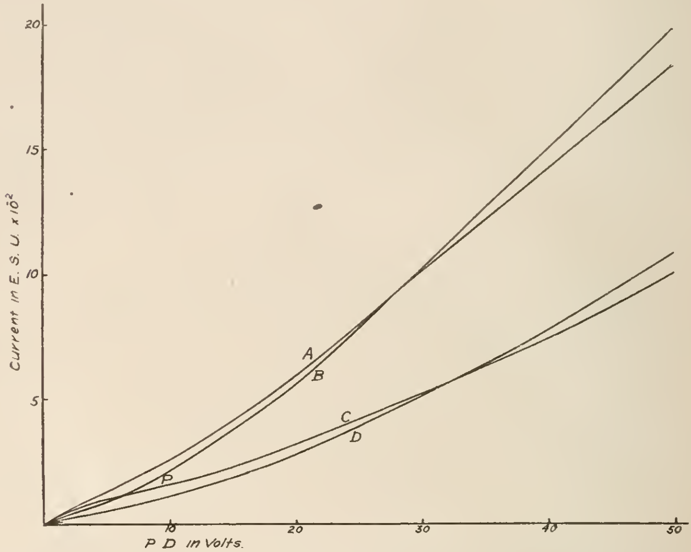

FIG. 3.—Current-Potential Curves with Electrodes 6 and 7 cm. apart.

was of the general form depicted in Fig. 1, the outer case being in electrical connection with the aluminum foil covering the mica shield over the cell which held the active preparation. The curves shown are drawn accurately through the experimental points, of which there are respectively 12, 11, 12, and 12 for curves A, B, C, and D. In order to avoid confusion, these points are not shown in the figure.

It is known that when α rays strike a metallic surface, or for that matter when they strike the molecules of a gas, δ rays are emitted with speeds ranging from zero upwards. In the case of metals, speeds as high as those corresponding to 2,000 volts have been recorded.[3] The first idea suggested by curves such as those of Fig. 3 is that of increase of conductivity of the gas with applied field, as a result of ionization by collision of the δ rays with the gas molecules. The mean free path of a slowly moving electron, as calculated from the kinetic theory of gases is, however, only of

[3] BUMSTEAD, *Phil. Mag.*, vol. 26, p. 233, 1913.

the order of 10^{-5} cm. at atmospheric pressure, and Franck and Hertz[4] have shown that this small mean free path is applicable to electrons with velocities as high as 5 or 10 volts. Insofar as the velocity contributed by the field is the velocity contributed during the passage of the electron over its mean free path, it may readily be verified that such small fields as were used in the present experiments would have but insignificant effects in boosting up the velocity of those δ rays which move too slowly to ionize, to the value 9 volts necessary for ionization. The forms of the current-potential curves receive a ready explanation, however, along the following lines:

Consider two plates A and B, the lower one (A) being covered with a radioactive substance. The α rays emitted produce ions in the gas, and they also produce δ rays in the plates A and B. δ rays may also be produced by any β particles emitted by the active substance, so that in general, both plates act as sources of δ rays. These δ rays, on account of their slow speed, do not travel far from the plates before such velocity as they have becomes reduced by collision to the normal velocity appropriate to temperature agitation.

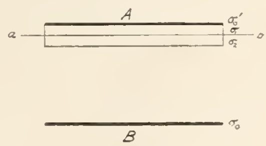

FIG. 4.

Suppose, to fix our ideas, that the plate B, Fig. 4, is positively charged, A being earthed, and let us confine our attention to a layer of negative electricity initially deposited near the plate A. This layer will be attracted by the plate A, owing to inductive action, and it will be attracted in the opposite direction by the forces of the field.

Let σ^1_0 and σ_0 be the charge densities on the upper and lower plates, respectively. Consider a column of gas whose length is perpendicular to the plates, and whose cross-sectional area is 1 sq. cm., and imagine the charge in this column divided by a horizontal plane ab into upper and lower amounts σ_1 and σ_2 respectively. Then the force will be zero on the plane in question when

$$2\pi\,(\sigma_0 - \sigma_0^1 - \sigma_1) = -2\pi\,\sigma_2$$

where due regard is paid to the sign of the sigmas.

If we take an origin on the plane ab and measure x downwards, we have for V the difference of potential between ab and the plate B,

[4] J. FRANCK AND G. HERTZ, *Deutsch. Phys. Ges.*, vol. 15, No. 9, p. 373, 1913, and *Deutsch. Phys. Ges.*, vol. 15, No. 14, p. 613, 1913.

$$V = \int_0^l 2\,(2\pi\,\sigma)\,dx \tag{1}$$

where l is the distance from ab to B and σ is here the charge contained between two horizontal planes 1 sq. cm. in area, one passing through the point x and the other in the plane ab.

Now, so long as x is below the layer where electrons are being deposited, the downward negative current-density at x is $i = 4\pi v\sigma\rho$, where v is the specific velocity of the negative carriers, and ρ is the volume density.

$$\text{Hence, } i = 4\pi\,v\,\sigma\,\frac{d\,\sigma}{d\,x} = 2\,\pi\,v\,\frac{d\,\sigma^2}{d\,x}$$

$$\text{and } \sigma^2 = \frac{i\,x}{2\,\pi\,v} + \text{constant}$$

The constant must be sensibly zero, since, in the steady state, both x and σ are sensibly zero at the lower surface of the layer of deposition if the latter is thin.

$$\text{Hence, } \quad \sigma^2 = \frac{ix}{2\pi v}$$

$$\text{and from (1). } V = 4\pi\left(\frac{i}{2\,\pi\,v}\right)^{1/2}\int_0^l x^{1/2}\,dx = \frac{8\,\pi}{3}\left(\frac{i}{2\,\pi\,v}\right)^{1/2} l^{3/2}$$

$$\text{Thus, } \quad i = \frac{9\,v\,V^2}{32\,\pi\,l^3} \tag{2}$$

If the layer of deposition is very near to the upper plate, l is the distance between the plates. V really differs from the true potential-difference between the plates by an amount which is comparable with the difference of potential between the upper plate and the plane ab, and which would be negligible compared with V, except for small values of the latter.

Since there is no conduction of electricity across the plane $x = 0$, we readily see that the electrons deposited above this plane all return to the upper plate, while those deposited below it constitute the current density i. The two current-densities when added (regardless of sign) make up the saturation current density I, which would be obtained for large differences of potential between the plates. I, of course, represents the rate of deposition of negative electricity per square centimeter of the layer.

It will be seen that the theory developed above makes the current decrease rapidly with the distance between the plates, and also makes it vary more rapidly with the potential than would

correspond to a linear law. The theory is very similar to that applicable to the current through a gas ionized by an incandescent solid;[5] the expression relating i and V is, in fact, the same in both cases, but in the treatment for the case of the ionization by incandescent solids, the portion of the current which returns to the plate is supposed to return as a result of the ions bombarding the plate in virtue of their temperature agitation. As to which form of treatment is the more applicable depends on the conditions. If the δ rays emitted from the plate in the present experiments become ordinary ions after their first impact with molecules, their mean free path will probably fall to such a small value that they can no longer return to the plate except by a process of diffusion under the influence of electrical forces. If, on the other hand, they are able to bombard the plate, both methods of action should be considered. As far as the measured current to the lower plate is concerned, however, the resulting expression is independent of the method of treatment, and the expression for the current is that given by (2), the simplest way of viewing the range of applicability of this formula being to remember that V is in error by an amount comparable with the potential drop in the double layer near the plate. As we have already remarked, each plate has a layer of ions in its vicinity, so that the errors in V tend to annul each other. It will, of course, be noted that only the layer next to the negatively charged plate functions in contributing to the measured current, the electrons shot into the other layer simply return to the plate, and so their net contribution to the current is zero. If the field between the plates is reversed, the layers which function as the origin of the current become reversed. The origin of the increase in current-density with potential-difference as indicated by (2) is, of course, to be found in the circumstance that, as the potential-difference is increased, more and more of the electricity deposited in the layer next to the negative plate is captured for the positive plate at the expense of the return current to the negative plate. The saturation current would be reached, as already remarked, when the whole of the electricity deposited was captured by the positive plate, although absolute saturation would also involve the driving away of that portion of the layer which was sufficiently near the plate to be able to send ions to it by bombardment. For absolute saturation, an enormous value of V would be necessary, and indeed the insulation of the gas would break down

[5] J. J. Thomson, *Conduction of Electricity Through Gases*, 2nd edition, pp. 207-209.

under the strain[6] before the necessary potential was reached. As already pointed out, however, the question of the importance of the current which returns to the plate by bombardment is one which depends upon the circumstances of the experiment.

In the present work the current is not entirely due to the δ rays, since the α particles ionize the gas, and the current resulting from this latter circumstance tends to increase less rapidly than the potential-difference. For very small potential-differences, we should expect the δ-ray current to play an insignificant part in the phenomenon, so that the current-potential curve would follow the law corresponding to the remaining part, and the current should accordingly increase less rapidly than the potential difference. As the potential-difference increases, however, the δ-ray effect, increasing as the square of the potential, will eventually predominate, and the current will increase more rapidly with the potential-difference than would correspond to a linear law, but will eventually attain a practical saturation. These are just the characteristics shown by the curves in Fig. 3.

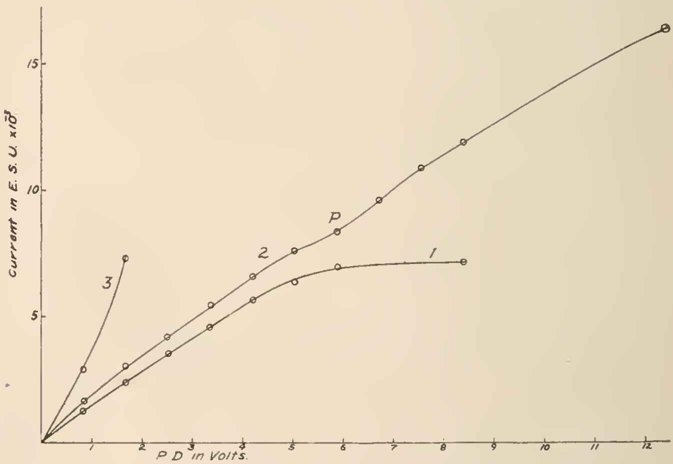

Fig. 5.—Current-Potential Curves obtained with Radium.

Since in these experiments the active material was sealed and covered with aluminum foil, the δ rays ultimately responsible for the phenomenon when the upper electrode was charged positively, were those coming from this foil and from the walls of the chamber. Of course, when the upper plate is far from the foil in the present

[6] *Cf.* J. J. Thomson, *Conduction of Electricity Through Gases*, 2nd edition, p. 213.

apparatus, the system cannot readily be considered as one with two infinite parallel plates; this would not, however, affect the general characteristics of the phenomenon.

That the phenomena exhibited by the curves in Fig. 3 are not limited to the case where ionization is produced by α rays, is shown by the curves in Fig. 5, where radium was the ionizing agent. The radium was sealed in a small glass tube, which in turn was encased for protection in a thin brass block. In each case a positive potential was applied to the walls of the ionization chamber, so that the δ-ray layer responsible for the effects under discussion was the layer formed at the surface of the other electrode, which in all cases was a wire. We should thus expect that the δ-ray effect would be enhanced by increasing the size of the wire electrode. The δ rays in the present case must be looked upon as being produced both by the γ rays direct, and by the β rays to which the γ rays give rise in the chamber.

Curve (1) was taken with a central electrode composed of a thin wire, the surface area being 0.4 sq. cm. It will be seen that it shows only a departure from linearity of the usual type. Curve (2) corresponds to a case where the central electrode was a wire of twice the surface area of that used in Curve (1); we should in this case, therefore, expect an increase in the δ-ray effect, and this is well shown by the upward tendency in the curve at the point P; for further increase in the potential, however, the curve shows a tendency in the reverse direction. In Curve (3), the central electrode was a thick wire of total surface area 1.3 sq. cm., i. e., about 3 times the surface area of that for Curve (1), and it will be observed that the δ-ray effect is very marked.

That the increase of apparent conductivity with potential-difference between the plates in the various cases we have discussed is really a δ-ray phenomenon, at any rate in part, and not the result of non-uniformity of the ionization in the ionization chamber, is further borne out by the following experiments:

The active preparation, which in this case was not hermetically sealed, was insulated from the base of the ionization chamber and covered with a piece of gauze connected with the wall of the chamber. It was thus possible to maintain a difference of potential between the gauze and the active material and determine, under these conditions, the current-potential curve between the gauze and the upper electrode. The "retard potential-difference," as we shall call it, between the gauze and active preparation was of

such a sign as to draw negative electricity towards the active material, and away from the gauze. In Fig. 6, A and B represent

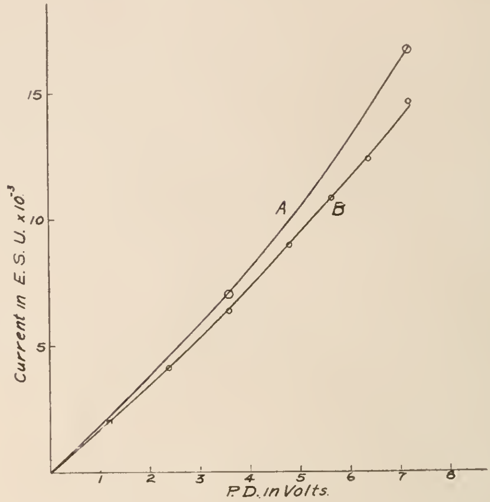

Fig. 6.—Current-Potential Curves with "Retard Potential-Differences."

respectively the current-potential curves for ionium with retard potential-differences of zero and 17 volts, all other conditions being the same. It will be observed that not only does the curve B fall below curve A, but the difference between the ordinates of the two curves forms a greater percentage of the whole ordinate for large potential-differences than for small ones, indicating that the effect of the retard potential-difference is to diminish the apparent increase of conductivity of the cell with increase of field. In the case of these experiments, the field in the ionization chamber was in a direction such as to drive negative electricity from the wall of the chamber to the central electrode, so that the δ-ray layer operative was the layer in the vicinity of the gauze and the chamber wall. The way in which this layer must be supposed to arise is by the α particles causing the emission of electrons from the sides of the meshes of the gauze as they pass through.

Now, in the meshes of the gauze, the lines of force must run somewhat after the fashion shown in Fig. 7. Some run from the active plate to the gauze, and some run there from the upper electrode. δ rays emitted so as to be entangled in the web of the upper field will obey that field, and electrons emitted so as to become entangled in the lines of force of the lower field will go

down to the active plate. The portion of the surface of the gauze available for the emission of δ rays is therefore drawn upon by the upper and lower fields, and it is easy to see that the stronger the lower field the more will its lines of force extend themselves over this available surface at the expense of the upper field. We should thus expect the δ-ray effect in the chamber, and consequently the upward tendency of the current-potential curves to decrease with increase of retard potential-difference. This is just what experiment shows to be the case.

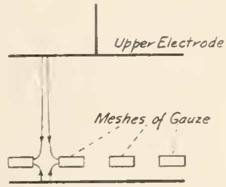

FIG. 7.

Another experiment which was performed, bearing out the above conclusions, is the following: The gauze used in the experiment already described was replaced by an aluminum plate bored with holes. The current-potential curves were obtained with two such plates. The plates had about the same total hole area, but in one of them the diameters of the holes were much smaller than in the other, so that there were many more holes. Under these conditions, not only was the δ-ray effect smaller with the small holes than with the large ones, but it was influenced to a negligible extent by the retard potential. Thus, to cite one example from many, for a difference of potential of 7.2 volts between the upper electrode and the wall of the chamber, a retard potential-difference of 20 volts produced 11 per cent diminution in the current in the case of the large holes, while in the case of the small holes, with all other conditions the same, a retard potential difference of 24 volts produced no observable effect on the current. The active substance used in this experiment was ionium.

The reason for effects such as those cited above is obvious on the view adopted. In virtue of the fact that the plate has an appreciable thickness, the holes partake somewhat of the nature of cylindrical channels. The lines of force of the upper field are not able to penetrate into these channels so far in the case of the small as in that of the large channels, so that the sum of the areas of the internal surface of the channels available for supplying δ rays to the space above is smaller for the small than for the large holes.[7] Again, the field below the plate is unable to extend its lines of force through the small channels so as to encroach upon the space which provides δ rays for the upper chamber. There

[7] There is, however, a circumstance which acts in the opposite sense. For a given total area, the sum of the circumferences of the holes is greater for the small than for the large holes.

is, in the channel, a sort of neutral territory, to which the lines of force of neither field can penetrate. We should thus expect, as experiment shows to be the case, that retard potential differences would have very little influence in the case of the small holes.

THE CURRENT WITH ZERO POTENTIAL-DIFFERENCE BETWEEN THE ELECTRODES.

If one of the electrodes be earthed and then insulated, the other one being maintained earthed, it will be found necessary to supply the insulated electrode with electricity in order to keep it at zero potential. We shall use the term "zero current" to denote this supply current which exists when there is no potential-difference between the electrodes. The zero current consists, in general, of two parts; a small part representing the ordinary volta effect, and a part resulting from the gain or loss of δ rays by the insulated plate. If the "zero current," for the upper electrode, is plotted against the distance between the electrodes, we should expect a sudden change in its magnitude for the distance at which the upper electrode lies in the neighborhood of the limit of the range of the α particles, since there the emission of δ rays by the α particles would commence.[8] This feature is well exhibited by Fig. 8, which represents the results for an uncovered layer of ionium, the upper electrode being a small brass cylinder of about 0.5 sq. cm. surface area. The abscissas represent the distance from the active layer to the electrode, and the distance from the origin to the point where the curve falls suddenly, of course, corresponds to the range of the α particles. The curve in Fig. 8 was not taken primarily with the object of determining the range, so that the distances recorded are only approximate. This method of determining the range of the α particles may have some advantages over that in which the α particles are detected by their effect on entering a shallow ionization chamber, for in the first place, no uncertainty is involved in knowing to which point in the ionization chamber measurements should be made, and in the second place, no trouble

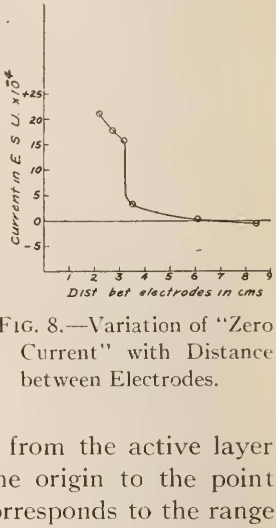

Fig. 8.—Variation of "Zero Current" with Distance between Electrodes.

[8] The actual gain of positive charge by the upper plate, owing to the absorption of α particles will readily be seen to be insignificant in the light of what follows.

arising from the difficulty of separating the ionization chamber from the rest of the apparatus is involved.

In attempts at an accurate determination of the range by this method, it would naturally be convenient to limit the beam of α particles to those traveling approximately perpendicular to the lower plate. This could easily be done by covering the active plate by a thick disc bored with holes.

THE MAGNITUDE OF THE δ-RAY EFFECT.

By measuring the "zero current" from the upper electrode when it lies within the range of the α particles, we can form a rough estimate of the number of δ rays emitted per second by all the α particles striking the plate; for, as shown by Figure 8, the contribution to the δ-ray current, under these conditions, is mainly that due to the α rays. In one experiment, in which a sealed layer of ionium covered with aluminum leaf was used, and in which the distance between the electrodes was 0.63 cm., a δ-ray current of 28×10^{-3} E. S. U. was measured, corresponding to a departure of about 6×10^{7} electrons from the upper plate per second. On the other hand, the saturation current between the electrodes was 0.34 E. S. U., so that there cannot have been more α rays passing through the space between the plates than would have been responsible for this saturation current. If q is the number of ions produced per second between the plates, $q = 0.34/e$, where e is the electronic charge (4.7×10^{-10} E. S. U.). Hence $q = 7.2 \times 10^{8}$. The position corresponding to the end of the range of the α particles, in the absence of the upper electrode, was determined by the method described on page 14, and was found to lie 2.6 cm. above the aluminum foil. Hence, the space between the upper electrode and the foil corresponded to the ionization path of the α particles comprised between distances 2.6 cm. and $(2.6 - 0.63) = 1.97$ cm. from the zero-energy end of the α-ray ionization curve. Making use of the data as obtained from the ionization curve for α particles, we find that the number of ions produced by an α particle over this part of its path is 3×10^{4}. This, of course, leaves out of consideration the fact that all of the α particles do not travel perpendicular to the plate, but we are at present only concerned with the order of magnitude of the effect, and while it would not be difficult to make an allowance for this fact, it would not be worth while to do so. Thus, even if the whole of the ionization between the plates were due to α particles, we should require an expulsion

of no more than $7.2 \times 10^8/3 \times 10^4 = 2.4 \times 10^4$ α particles per second into the space between the electrodes, to account for the value of q observed. Since, as above shown, 6×10^7 δ rays were liberated from the upper plate per second, with a velocity sufficient to enable them to get away, 1 α particle must have been responsible for the emission of at least $6 \times 10^7/2.4 \times 10^4 = 2500$ δ particles, although of course, the action may in some cases be indirect, as when slow speed δ rays are produced by higher speed δ rays which were themselves produced by the α particles. It is further to be noted that the number of δ particles per α particle as above estimated, corresponds only to those emitted by the α particle as a result of the energy left in it when it reaches the plate from which the δ particles are emitted.

There is nothing very astonishing from a theoretical point of view in the largeness of the number of δ particles emitted by an α particle, for we know that 1 α particle will produce about 2×10^5 ions in air, where the ionization-energy is only slightly less than in a metal. In fact, it might rather be expected that the determining factor in deciding the number of δ particles which make their appearance in the case of a metal would be the facility with which those particles which are produced well below the surface of the metal can get out. Thus, many of the δ particles which have their origin at the end of the range of the α particles in the metal will be unable to get free.

Duane,[9] working in air at low pressures, found an emission of only about 50 δ particles per α particle, and Hauser,[10] also working in air at low pressures, found an emission of about 60 δ particles per α particle. More recently Bumstead[11] has come to the conclusion that the number of δ particles mitted by an α particle is much larger than those found by former observers. It is not improbable that the facility with which the δ particles are emitted from a metal depends upon the pressure and nature of the gas present, and possibly upon the nature of the metal as well. The very marked effects of surface layers encountered in the case of photo-electric phenomena would naturally lead one to anticipate similar effects in δ ray emission, which theoretically should have many points in common with photo-electric emission, and, indeed, Bumstead and McGougan have invoked surface layers for the purpose of coordinating certain other phenomena in δ-ray emission.[12]

[9] *Le Radium*, vol. 5, p. 65, 1908.

[10] *Phys. Zeit.*, vol. 12, p. 466, 1911.

[11] *Phil. Mag.*, ser. 6, vol. 26, p. 233, 1913.

[12] *Phil. Mag.*, ser. 6, vol. 24, p. 462, 1912.

It is not improbable that some of the difficulties which have been encountered in the use of radioactive resistances may arise from the action of these surface layers. Thus, in the present experiments, it was found that the "zero current" as measured in the experiments described on page 5 increased from 12×10^{-3} E. S. U. immediately after cleaning and sandpapering the upper electrode, which was of aluminum, to 28×10^{-3} E. S. U. on the following day. This change was not the result of alteration in the volta effect, as the current resulting from the volta effect was very small compared with the zero currents here referred to. After the aluminum electrode had been in the ionization chamber for two or three days the readings commenced to become erratic, and to vary with the time which the potential had been applied. The erratic effects at once disappeared on re-sandpapering the electrode. The effects referred to amounted to only a few per cent, but they were much greater than the limits of accuracy of the measurements in other respects. In these particular experiments, the greatest care was taken to exclude anything which would give rise to oily vapors, as such substances are known to cause considerable trouble in photo-electric measurements.[13]

It is thought that aluminum is an unsuitable metal to use for work of this kind. Its main advantage lies in the fact that the foil has a small stopping power for α particles; it consequently forms a suitable covering for the mica window in the cell containing the active material, and the use of aluminum here renders its use desirable in the upper electrode. On the other hand, the strong action which aluminum exhibits in occluding gas is familiar in work at high vacua, and that a strong volta effect is obtained between a piece of freshly sandpapered aluminum and a piece which has not been sandpapered for a few days, is well known, and indicates that the air has some very marked influence on the surface actions of this metal. For these reasons an ionization chamber has been constructed in which the electrodes are of silver. The sealed specimen of ionium was covered with silver foil held down by a silvered copper ring which replaced the aluminum ring referred to on page 5. With this cell, the constancy was enormously better than when aluminum was used. For a constant potential difference of 6 volts, the current showed a change of about 5 per cent in the first 3 days after sandpapering, but the change during the third day was extremely slow, and obser-

[13] Stuhlmann and Compton, *Phys. Rev.*, ser. 2, vol. 2, p. 199, 1913.

vations taken on the same day repeated themselves with great regularity.

DEPENDENCE OF THE SATURATION CURRENT UPON THE SIGN OF THE APPLIED POTENTIAL-DIFFERENCE.

It is usually found that the saturation current between two parallel plates depends upon the sign of the potential of the active plate, being greater when the active plate is negative. This fact is illustrated by the curves in Figure 2, and its explanation is not far to seek. When the lower plate is negatively charged, it is the δ-ray layer in its vicinity which is operative while when the lower plate is positively charged the δ-ray layer in the vicinity of the upper plate is the one which is operative. Now we should naturally expect a greater total δ-ray emission from the active plate, or from the foil covering the active plate and the walls of the chamber which are continuous with the foil, and from which secondary δ-ray emission may take place than from the upper electrode; hence, the saturation current may be expected to be greater when the active plate, or the foil covering it, is negatively charged.

THE VARIATION OF THE CURRENT WITH THE DISTANCE BETWEEN THE ELECTRODES.

The curve representing the relation between the current and the distance between the electrodes for a given difference of potential between them, presents certain points of theoretical interest. In Fig. 9, the curve shown is for ionium, which was uncovered except for a layer of gauze. The upper electrode was a brass cylinder of total area about 0.5 sq. cm. The currents which are here corrected for the "zero" current show the well marked diminution as the upper electrode is moved out of the region to which the α particles reach, and consequently into the region where the air is poorly ionized.

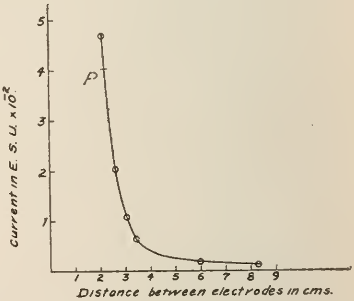

Fig. 9.—Variation of Current with Distance between Electrodes.

Now if, for example, the upper electrode in a position such as that represented by the point P, is moved 0.1 mm., the current will change by 3 per cent, and it will readily be surmised that an alteration of the range of the α particles amounting to 0.1 mm. will have a very similar effect. Now if the range of the α particles

is inversely proportional to the number of molecules per cubic centimeter, then, at constant pressure, it should vary directly as the absolute temperature, so that if the range at ordinary temperature is 3 cm., an alteration of 1° C. will produce an alteration of about 0.1 mm. in the range. Accordingly we should expect that such an alteration in temperature would be accompanied by an alteration of about 3 per cent in the current.

Remarks precisely analagous to those concerning variation with temperature apply to variation with pressure, and these considerations serve to illustrate how it may happen that the temperature coefficient, or pressure coefficient, of a Bronson resistance may be very large for certain positions of the electrodes. Theoretically, however, so long as the cell is hermetically sealed, so that the total *amount* of gas is kept constant, the range of the α particles should be constant, and the cell should not be subject to changes of the type above discussed, even though the pressure or temperature may vary.

ON THE POSSIBILITY OF SECURING A LINEAR RELATIONSHIP BETWEEN THE CURRENT AND THE POTENTIAL-DIFFERENCE BETWEEN THE ELECTRODES.

We have seen that in the ordinary type of Bronson cell the shape of the current potential curve is controlled by two circumstances, (1) the ordinary diminution of apparent conductivity with increase of potential-difference, and (2) the apparent increase of conductivity with potential-difference as a result of the δ-ray effect. By choosing the position of the electrode suitably, we should be able to make these effects compensate to the extent of causing a linear relationship over a fairly wide range of potential. This is probably the reason that other investigators were automatically led to adopt certain dimensions as the most desirable for Bronson cells. For the purpose of securing linearity in practice, we have found it convenient to make the upper electrode in two parts. One part consists of a silver disc 5 cm. in diameter supported by a silver tube. In this tube slides a silver rod with a small disc, 2 cm. in diameter, at its lower end. The two discs form the compound upper electrode, and with the arrangement adopted, the positions of the discs may be varied independently. The silver tube is prolonged at its upper end into an iron tube which slides in another iron tube fixed in an amber plug, so that the joint may be mercury sealed if necessary. The lower electrode is similar in construction to that already described on page 4,

except that, as pointed out on page 17, the sealed radioactive specimen is covered with silver foil, held down by a silvered copper ring. The outer case of the cell is of iron, so that all joints may be mercury sealed when necessary, but this outer case is provided with an inner copper member which is silvered, so that none but silver surfaces function in the electrical actions of the cell.

If the large disc is well out of range of the α particles, and the small disc is coincident with it, the portion of the curve for low potential differences shows, in general, a departure from linearity, of the ordinary type. On moving the small disc down, the δ-ray effect becomes increased, and the curve tends to straighten out. By choosing a suitable position for the small disc, a curve may be obtained which is linear over a range considerably greater than is possible with a single electrode.

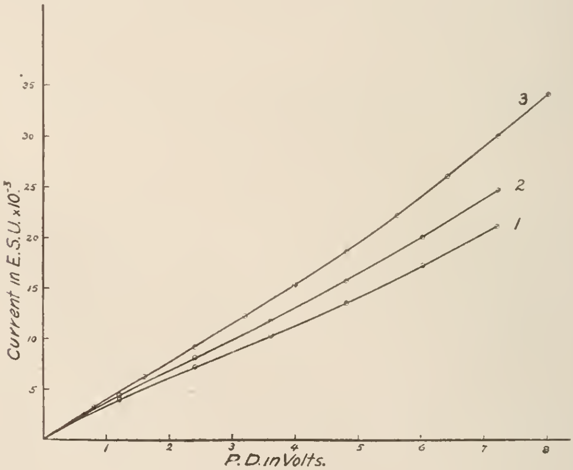

Fig. 10.—Current-Potential Curves obtained with Compound Electrode.

The three curves shown in Fig. 10, illustrate the behavior of the silver cell. All three curves are corrected for zero current. Calling a and b the distance from the foil to the larger and smaller discs respectively, the values of a and b for the three curves are as follows: Curve 1, a = 5.2 cm., b = 1.05 cm. Curve 2, a = 5.2 cm., b = 1.45 cm., Curve 3, a = 4.6 cm., b = 1.05 cm.

It will be seen that, over a range of 4 volts, Curve 3 shows an approximation to linearity which is very good when the high resistance of the cell is taken into account. The normal tendency towards saturation in the absence of the δ-ray effect is, of course,

such that departure from linearity becomes prominent for lower potential-differences in the case of high-resistance cells than in the case of low-resistance cells.

SUMMARY.

(1). At atmospheric pressure, the current-potential curves for a radioactive cell, with the electrodes far apart, show, in general, a departure from linearity, of the ordinary type, for low potential-differences, but an apparent increase of conductivity with potential for higher potential-differences. It is shown that the characteristics of these curves can be explained as a result of the δ-rays emitted from the surface of the metal.

(2). The number of the δ-rays emitted per α particle, either directly or indirectly, is much larger than has been found at low pressure, and amounts to more than 10^3 δ particles per α particle, in the case of ionium.

(3). The large δ-ray emission is attributed to the effect of the gas in facilitating the escape of the electrons from the metallic surfaces, and the conclusions are borne out by experiments in which it is shown that the δ-ray effect varies with the interval which elapses between the time when the electrodes are sandpapered and the time when they are used. As a result of the properties exhibited by aluminum in occluding gas, it is found that this metal is bad for use in radioactive cells.

(4). It is shown that an estimate of the range of an α particle may be made by noting the distance between an active layer and the point to which the other electrode reaches, when the current with no difference of potential between the electrodes shows a sudden change with alteration of that distance.

(5). Certain sources of variations in Bronson cells are discussed:

a. It is shown that, even though the cell be hermetically sealed, the active material should be sealed off from the cell itself in the case where an emanation is emitted.

b. It is shown that for certain positions of the electrodes, Bronson cells may be expected to show large changes with variations in temperature and pressure, unless they are hermetically sealed.

(6). A form of cell suitable for securing a linear variation of current with potential-difference over a wide range is described.

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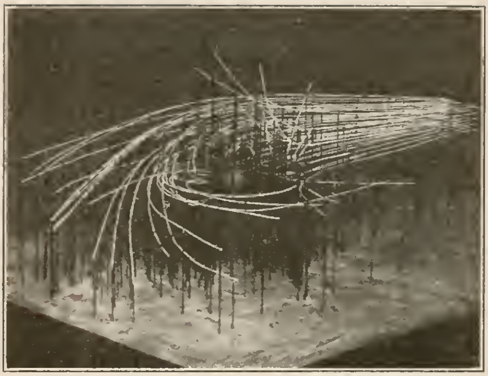
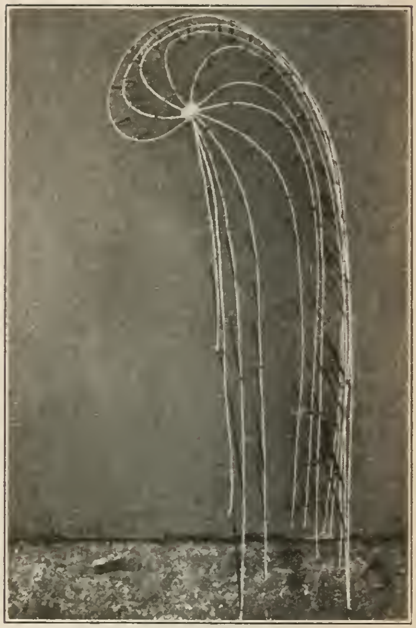
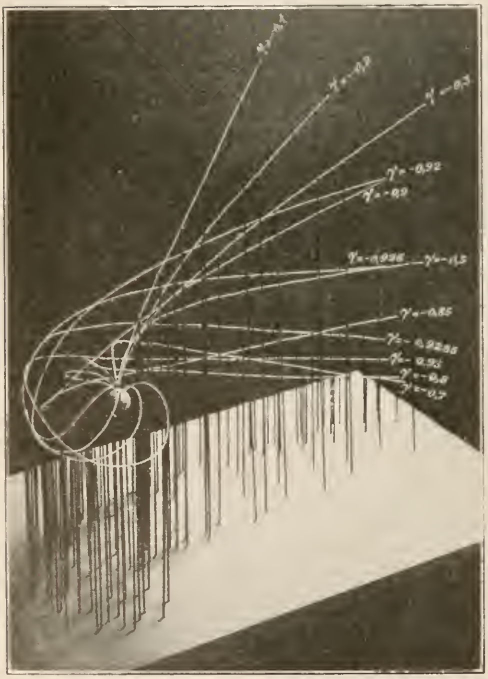
Carnegie Institution of Washington.



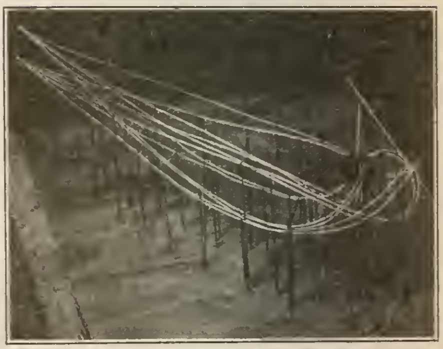
a.



b.



c.



d.

Corpuscular Theory of the Aurora Borealis.

CORPUSCULAR THEORY OF THE AURORA BOREALIS.

By Carl Störmer, *Kristiania*.

INTRODUCTION.

It appears that the German physicist, Goldstein,[1] was the first to publish the idea that the Sun sends out into space electrical rays analogous to cathode rays, and that we may thus explain the mysterious connection between variations in solar activity and corresponding fluctuations in the magnetic and electric phenomena on the Earth. Some years later the Danish meteorologist, Adam Paulsen, from his auroral observations in Greenland was led to the hypothesis[2] that the aurora is due to cathode rays; but instead of assuming that the rays came from the Sun, he believed that they originated in the upper strata of the atmosphere.

Next, in the year 1896 Kr. Birkeland made his remarkable experiments with cathode rays in a magnetic field. He first found that a magnetic pole had an effect on a beam of parallel cathode rays analogous to that of a lens upon a beam of light, viz., to make the rays converge towards a point. This phenomenon led him to the idea[3] that the aurora borealis was due to a similar effect of the Earth's magnetic field on cathode rays coming from the Sun. In order to test his hypothesis, Birkeland exposed a small spherical electromagnet to a stream of cathode rays, and found a series of facts showing analogies to the shape and nature of the aurora. The aurora-belts in particular were very beautifully produced. These remarkable experiments, which gave the first really good support to the corpuscular theory of aurora, were described on pages 39-42 of the paper "Expédition Norvégienne, 1899-1900, pour l'étude des aurores boréales.[4] Notwithstanding that these remarkable experiments tend to show that the aurora is a direct effect of the precipitation of cathode rays in the upper air, Birkeland regarded the aurora as being caused rather by secondary cathode rays produced by strong electric currents in the upper atmosphere;[5] in his later publication, however, he arrived at

[1] "Über die Entladung der Electricität in verdünnten Gasen," in *Wiedemanns Annalen*, vol. XII, p. 266, for the year 1881.

[2] See his paper: Sur la nature et l'origine de l'aurore boréale, Kjøbenhavn, 1894.

[3] See *Archives des sciences physiques et naturelles*, 1896, p. 497, Geneva.

[4] *Cf. Videnskabsselskabets Skrifter*, 1901, Kristiania.

[5] *Idem*, pp. 60 to 74.

the conviction that the aurora is a *direct* effect of the electric rays from without.[6]

Arrhenius, in 1900, published his hypothesis that the Sun continually sends forth small electrified particles, varying in size from one ten-thousandth to one thousandth of a millimeter in diameter, and that these particles are repelled from the Sun by the pressure of light, and that on reaching the Earth's atmosphere cause aurora.[7]

At the beginning of 1903, I became extremely interested in Birkeland's theory of the aurora; knowing that the phenomenon of the concentration of cathode rays towards a single pole had been mathematically treated by Poincaré, I thought it might be worth while to determine mathematically the trajectories of electric corpuscles in the magnetic field of the Earth, hoping in this way to find again not only the details of Birkeland's experiments, but also the principal features of auroras and of magnetic storms. My first results appeared to be promising.[8] The work has subsequently been continued, and has been followed by two expeditions undertaken to Bossekop in 1910 and 1913.

The theory of auroras was again taken up by Birkeland in his large work published in 1913, "The Norwegian Aurora-Polaris Expedition, 1902-1903," second section, chapter IV.

As regards the nature of the electric rays causing aurora, very interesting arguments in favor of positively-charged particles have been put forward by Vegard.[9]

In the following paragraphs a résumé of my theoretical work from 1904 until 1912 will be given.

2.—SIMPLIFYING HYPOTHESIS.

If we assume that the Sun sends out into space large quantities of electrical corpuscles, the mathematical problem of finding the trajectories of these corpuscles is an extremely difficult one to solve in its most general form. As I pointed out in my Geneva paper of 1907, the natural way of proceeding would be first to endeavor to solve the problem in a series of simplifying hypotheses, and after that to deal with the cases in which the simplified hypotheses are abandoned one by one in order to obtain the real condi-

[6] *Cf. The Norwegian Aurora-Polaris Expedition*, 1902-1903, vol. 1, second section, p. 603, 1913.

[7] *Öfversigt af Kong. Vetenskaps-Akademiens Handl.*, Stockholm, 1900.

[8] *Cf.* Sur le mouvement d'un point matériel portant une charge d'électricité sous l'action d'un aimant élémentaire, *Videnskabsselskabets Skrifter, 1904.*

[9] On the properties of the rays producing aurora borealis, *Phil. Mag.*, Feb., 1912.

tions of Nature. As simplifying hypotheses, I chose the following in my Geneva paper:

(a) The motions of the Earth and the Sun are considered negligible, so that only their relative positions come into consideration; in fact, the speed of the electric corpuscles is supposed to be so great that the relative position does not sensibly change during the time taken by a corpuscle to pass from the Sun to the Earth.

(b) The corpuscles are not affected by any forces other than the Earth's magnetism, and they follow the laws observed by the motion of cathode particles in a stationary magnetic field.

(c) The Earth's magnetism, in accordance with Gauss's hypothesis, is considered as caused exclusively by magnetic masses in the interior of the Earth, so that we have the known expansion of the magnetic potential outside the Earth in a series of spherical harmonic terms containing ascending powers of $1/r$, r being the distance of the point from the Earth's center. In the mathematical analysis only the principal term of this series is used, which means that, for our purpose, the Earth's magnetic field may be considered as equivalent to that of a uniformly magnetized sphere, or what amounts to the same thing,[10] to that of an elementary magnet at the Earth's center with its magnetic axis coinciding with that of the Earth. This approximation will hold good at great distances from the Earth, because the other terms of the potential expansion containing higher powers of $1/r$ will be negligible as compared with the principal term.[11]

The problem by these hypotheses is reduced to *a study of the trajectories of electric corpuscles in a field of an elementary magnet.* We have here a problem analogous to that solved by Poincaré, viz., to find the motion of electric corpuscles in the field of a *single magnetic pole*, but our problem is far more difficult of solution. Direct studies of the trajectories by means of their differential equations provide us, nevertheless, with good information as to qualitative properties, and as regards more quantitative details the graphical and numerical methods of integration have been of fundamental importance.

3.—EQUATIONS OF MOTION.

The motion of electric corpuscles in the field of an elementary magnet is governed by a system of differential equations which are easily found. Let us use the system of fundamental units—centimeter, gram, and second, and let M be the moment of the elementary magnet, and H and ρ be two corresponding values of the magnetic force and the radius of curvature at a point of the orbit where the tangent is normal to the magnetic force; further, let c be given by the equation

[10] *Cf.* MAXWELL'S *Treatise on Electricity and Magnetism*, vol. I., paragraph 143, and vol. II, paragraph 675.

[11] For the details, see paragraph 1 of my Geneva paper, 1911-1912.

$$c = \sqrt{\frac{M}{H\rho}}$$

As is well known, the product $H\rho$ is a constant along the path of the corpuscle in motion and is characteristic of it. Let the elementary magnet be placed at the origin of a rectangular system of Cartesian coordinates with its axis along the Z-axis (Fig. 1), and with its south pole pointing in the direction of positive z. Then if the coordinates x, y, z, the radius vector r, and the arc s of the trajectory, are measured with the length c cm. as unit of length, the differential equations defining the trajectory of the corpuscle will be, if the charge is *negative*:

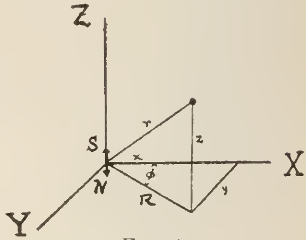


FIG. 1.

$$\left.\begin{aligned} r^5 \frac{d^2x}{ds^2} &= 3\,yz\frac{dz}{ds} - (3z^2 - r^2)\frac{dy}{ds} \\ r^5 \frac{d^2y}{ds^2} &= (3\,z^2 - r^2)\frac{dx}{ds} - 3\,xz\frac{dz}{ds} \\ r^5 \frac{d^2z}{ds^2} &= 3\,xz\frac{dy}{ds} - 3\,yz\frac{dx}{ds} \end{aligned}\right\} \qquad \text{I}$$

For a positively-charged corpuscle the signs of the second members of the equations must be reversed; but the same effect may be obtained by changing x into $-x$, i. e., by changing the positive direction of the X-axis. Hence the trajectories of positive corpuscles, for the same value of c will be symmetrical to the trajectories of negatively-charged corpuscles relatively to a plane through the Z-axis. It is of course sufficient to study the trajectories defined by system I.

By introducing polar coordinates R and ϕ, given by

$$x = R\cos\phi \qquad y = R\sin\phi$$

and integrating, we get for the angle ϕ (Fig. 1) the equation

$$R^2\frac{d\phi}{ds} = 2\gamma + \frac{R^2}{r^3} \qquad \text{II}\,a$$

and for R and z the system

$$\left.\begin{aligned} \frac{d^2R}{ds^2} = \tfrac{1}{2}\frac{\partial Q}{\partial R} \qquad \frac{d^2z}{ds^2} = \tfrac{1}{2}\frac{\partial Q}{\partial z} \\ \left(\frac{dR}{ds}\right)^2 + \left(\frac{dz}{ds}\right)^2 = Q \end{aligned}\right\} \qquad \text{II}\,b$$

where γ is a constant of integration and Q is a function of R and z given by the equation

$$Q = 1 - \left[\frac{2\gamma}{R} + \frac{R}{r^3}\right]^2$$

The problem of finding the trajectories is thus reduced to the integration of the system IIb, which can be done by the integration of a differential equation of the second order and a quadrature. Then ϕ is found from the equation IIa by a new quadrature. But even without integrating the equations, it is possible, as will be shown, to draw very important conclusions directly from the equations.

4.—REGIONS OF SPACE BEYOND WHICH THE TRAJECTORIES CANNOT GO.

The equation II a will give us the first important result for the general discussion of the trajectories. For if we call the angle between the tangent in the direction of motion and the plane through its point of contact with the trajectory and the Z-axis θ, we have $\sin\theta = \dfrac{R\,d\phi}{d\,s}$; the equation II a then gives us the formula

$$\sin\theta = \frac{2\gamma}{R} + \frac{R}{r^3}$$

Now along a trajectory, $\sin\theta$ cannot be less than -1, nor greater than $+1$; the trajectory must then be confined to the region of space where

$$-1 \leqq \frac{2\gamma}{R} + \frac{R}{r^3} \leqq 1$$

We will call this region Q_γ. *To each value of the constant of integration γ we thus obtain a corresponding region Q_γ and no trajectory corresponding to the same value of γ can get beyond this region.*

As regards the value of γ for a given trajectory, it can be found immediately from the equation

$$2\gamma = R\sin\theta - \frac{R^2}{r^3}$$

by substituting on the right side the values R, r and θ for an arbitrarily-selected point of the trajectory. The detailed study of all forms of the region Q_γ for values of γ between $-\infty$ and $+\infty$ will be found in my Geneva paper of 1907. Fig. 2 shows sections through the Z-axis of some of the most characteristic regions Q_γ; these regions are described by the white parts when rotated about the Z-axis.

The discussion of the regions Q_γ show in particular that only those corresponding to

$$-1 < \gamma \overline{\leq} 0$$

are open from the origin to infinite distance; the others are either closed or do not reach the origin of the system of coordinates.

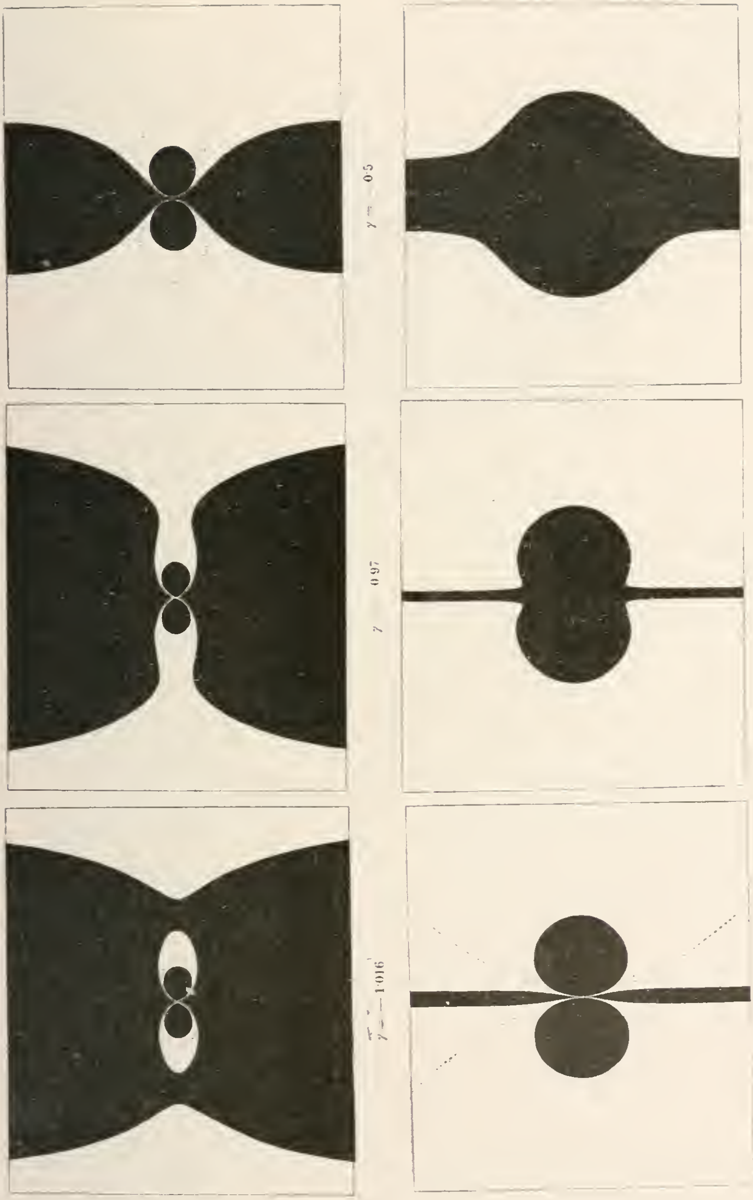
5.—IMPORTANT MECHANICAL INTERPRETATION OF THE EQUATIONS FOR R AND z.

Still more useful information concerning the trajectories is obtained if we give a suitable mechanical interpretation of system IIb. Let us interpret the arc s as the time, and R and z as the Cartesian coordinates of a material point p in a plane; *then system IIb defines the motion of that point under the action of a force derived from the function of force* $\frac{1}{2}Q$.

As a plane of this kind we may choose an arbitrary plane ORZ through the Z-axis. Further, let P be the corpuscle moving along the trajectory T, and let us pass a circle through P parallel to the XY-plane, and with its center on the Z-axis. Then p will be the point of intersection of this circle and the plane ORZ, and when the corpuscle P moves with constant velocity along T, the corresponding point p moves in the plane ROZ according to the above-mentioned mechanical law, and will describe a certain plane curve K. Vice versa, when we know the shape of the curve K, the form of the corresponding trajectory T in space is easily found by the formula for $\sin\theta$. To each curve K there are in general two corresponding sets of trajectories, each comprising all trajectories that can be obtained from one of them by rotation around the Z-axis; the first set corresponds to a motion along K in one direction, the second to a motion in the opposite direction, and the two sets are symmetrical to each other with reference to the fixed plane ORZ.

Now the study of the curves K is relatively easy when the level-lines $Q = h$ are drawn for a series of equidistant values of the constant h; these lines are situated exclusively in that part of the plane lying within the region previously called Q_γ, and in particular $Q = 0$ lies on the boundary of this region.

For the general study of the trajectories, we have computed and drawn such level-lines corresponding to the values $h = 0$, 0.1, 0.2, 0.3, ... 0.9 and 1, for a series of characteristic values of the constant of integration γ. In order to facilitate the mathematical interpretation, we have drawn the



$\gamma = 0{\cdot}5$
$\gamma = 0{\cdot}2$
$\gamma = 0{\cdot}97$
$\gamma = 0{\cdot}03$
$\gamma = -1{\cdot}016$
$\gamma = 0{\cdot}05$

Fig. 2.

parts between successive level-lines in graduated shades, white nearest to the line $Q = 1$, and dark nearest to the line $Q = 0$. In the essay published in the Inaugural Lectures of the Rice Institute these fields of force can be seen on a series of plates. The force acting on the point p will thus always be directed normally to the level-lines, and towards the lighter parts, and its strength will approximately vary in inverse proportion to the breadth of the spaces between two consecutive level-lines. The motion of the point p will be very much like the motion of a small sphere rolling without friction on an uneven surface, where the level-lines indicate the shape as on geographical charts, the valleys being marked by light and the higher regions by darker shading. The utility of these considerations in the general discussion of the trajectories can be seen in the essay mentioned above.

6.—GRAPHICAL AND NUMERICAL INTEGRATION.

The above methods are useful for the qualitative discussion of the trajectories. With respect to the quantitative investigation, however, they are insufficient. Yet even without being able to integrate the differential equations of motion, we have methods for finding the trajectories with any desired degree of accuracy. These are *the methods of graphical and numerical integration of differential equations*. The former should be employed when a preliminary and not very exact view is required; the latter, which is more laborious, when the greatest possible accuracy is required.

The method of graphic integration employed in our researches is described in a paper[12] published in 1908; it is based on a further development of a method given by Lord Kelvin, and it makes use of a simple construction of the radius of curvature. The method of numerical integration is described in detail in my Geneva paper of 1907, and in the publication of all the extensive computations of trajectories in *Videnskabsselskabets Skrifter*[13], Kristiania, 1913 and 1914.

7.—GENERAL VIEW OF THE TRAJECTORIES.

In addition to the theoretical study of the trajectories, very extensive work has been done in computing trajectories by means of the method of numerical integration. More than 5,000 hours have been spent by my assistants and myself in this most tedious

[12] On the graphic solution of dynamical problems, *Videnskabsselskabets Skrifter*, 1908.

[13] Résultats des calculs numériques des trajectoires des corpuscules électriques dans le champ d'un aimant élémentaire, I, II and III, with 2 figures and 25 plates.

and laborious task; an extract of the computations is now accessible in the above-mentioned publications of 1913 and 1914, but the results were previously given in my Geneva paper of 1907. It is impossible to enter into details here, and only a short résumé can be given.

For applications to the aurora the first calculations were made with the object of finding the trajectories of corpuscles coming from infinite distance and reaching the origin. Several series of such trajectories, issuing from a distant point, were computed, but without any great success. After approaching more or less to the origin, the trajectories in general receded; and only in a few cases were we able to obtain trajectories that approached near enough to verify theoretical conclusions as to the shape of the orbits near the elementary magnets. The latter were similar to the well known geodetic lines of a cone of revolution, with a very small opening, as seen in Fig. 3.

FIG. 3.

A view of a group of trajectories towards the origin is shown in Plate I, *a*. The origin is supposed to be at the center of the sphere, and the Z-axis parallel to the supporting dark pins. The trajectories are white. This model was constructed by the aid of the graphic method of integration, and is discussed in my essay contained in the Inaugural Lectures of the Rice Institute.

Certain characteristic features are seen in this model. First, the large group of trajectories turning round the nocturnal (evening and night) hemisphere of the globe, the trajectories being supposed to come from the Sun. In the neighborhood of this group there are trajectories encircling the globe in undulating fashion, and lying near the circular orbit seen in the view. On the morning side we have another series of trajectories bending abruptly away from the globe. Near the early afternoon side is seen a whirl, in the center of which trajectories approach the globe in spirals, as shown in Fig. 3.

8.—TRAJECTORIES PASSING THROUGH THE ORIGIN.

For application to the aurora the problem of finding the trajectories of *corpuscles coming from infinite distance and reaching the origin* was of fundamental importance. For a long time this

problem resisted all my efforts, but at last I succeeded in obtaining the following results:

For each negative value of the constant γ there are in general two curves K passing through the origin and symmetrical with respect to the R-axis. For each curve K there are two corresponding trajectories in space T_1 and T_2, T_1 for a motion towards the origin, and T_2 for a motion from it; T_1 and T_2 are symmetrical with respect to a plane through the Z-axis. Corresponding to T_1 we have further a set of trajectories all congruent with T_1 and obtained by rotating T_1 round the Z-axis; in the same manner T_2 gives a set of congruent trajectories.

The study and computation of all these trajectories are ex-

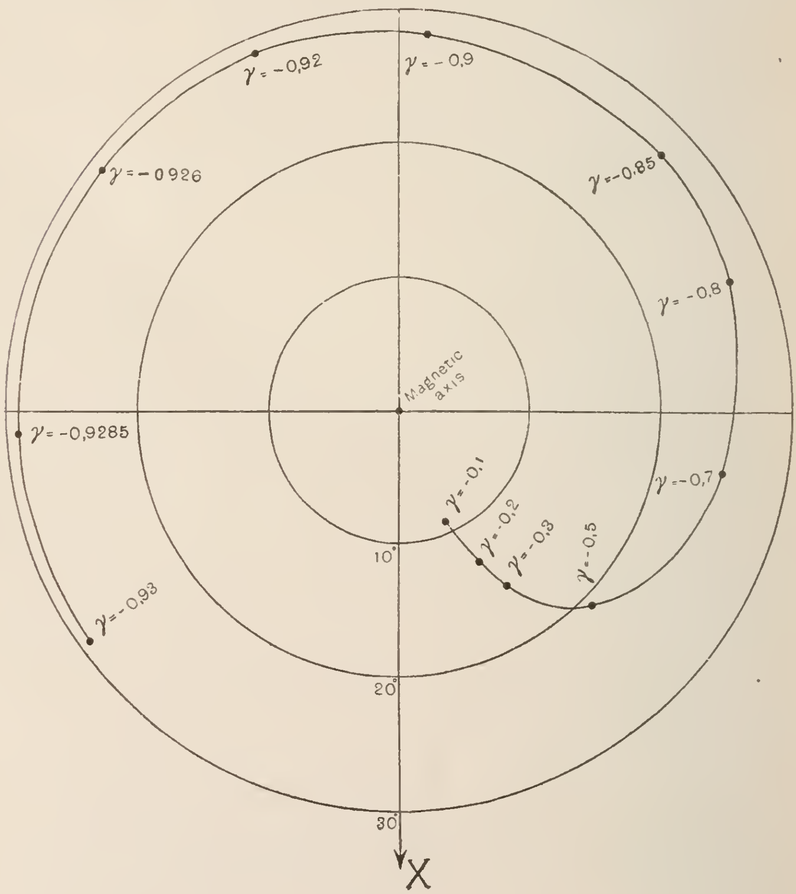


FIG. 4.

plained in detail in my Geneva paper of 1907, and especially in the paper "Résultats des calculs numériques, etc," I, *Videnskabs-selskabets Skrifter*, 1913. The computed trajectories are shown on the wire model, Plate I, *b* and *c*. The origin is in the center of the small sphere, and the XY-plane is parallel to the plane of the model, so that the dark supporting pins are parallel to the Z-axis. The trajectories are turned round the Z-axis in such a manner that they all pass the XZ-plane at a point the distance of which from the origin is about 28.8 (selected for application to the aurora borealis).

The distribution of the points of intersection of the trajectories with the surface of the small sphere is shown on a larger scale in Fig. 4. The computed trajectories are only *the simplest ones* corresponding to the values of γ written by the side. *For γ between — 0.93 and — 1 there is an immense number of remarkable trajectories that have not yet been studied in detail, and which have many curious forms.*

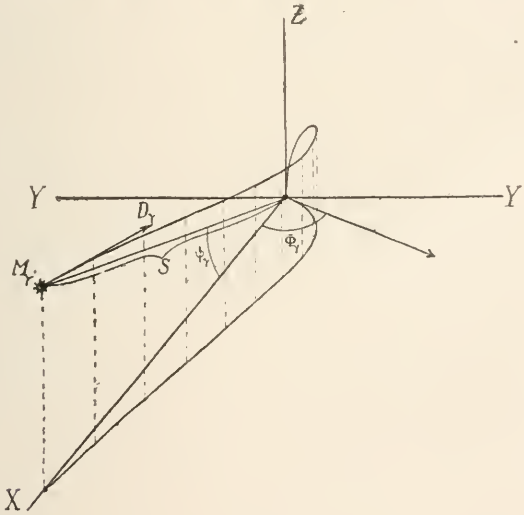


FIG. 5.

For instance, a corpuscle following a trajectory of this kind may pass round the globe many times in passing under and over the XY-plane before reaching the origin; others may approach in spirals and then recede before finally reaching the origin, etc.[14]

The series of trajectories already computed for γ varying from 0 to — 0.93, now affords us very valuable material for application

[14] A trajectory like this corresponding to γ = — 0.94 is published in the above mentioned paper of 1913.

to the aurora. It is necessary to give some quantitative results even at this stage. In order to explain the notations used, let (Fig. 5) M_γ be the point of intersection of the trajectory with the XZ-plane, the distance of which from the origin is about 28.8. Further, let D_γ be the direction of the tangent at that point in the direction of motion towards the origin. By ψ_γ we denote the angle between the X-axis and the radius vector to M_γ, and by ϕ_γ the angle described by a plane through the Z-axis and the corpuscle, when the latter moves from M_γ to the origin. Finally, let α_γ be the angle between the Z-axis and the radius vector from the origin to the point of intersection of the trajectory with the surface of the small sphere, shown on Plate I, *b*. Then if γ varies from zero to -0.93, all these values will be functions of γ that can be tabulated from the computations. The angle α_γ in particular is given with sufficient accuracy by the formula[15]

$$\sin \alpha_\gamma = \sqrt{-2\gamma r_0} \tag{1}$$

where r_0 is the radius of the small globe. We then obtain the following table, r_0 being in the model equal to 0.125:

γ	− 0.1	− 0.2	− 0.3	− 0 5	− 0 7	− 0.8	−0 85	− 0 9	− 0 92	−0.926	−0.9285	−0 93
ψ_γ	+52°6	+35°6	+21°.5	− 3°4	−20°1	− 14°9	− 3°2	+ 15°3	+ 8°.8	− 5°.2	− 15°.2	− 13°.2
ϕ_γ	−21.2	−27.1	−31.4	−45 4	−79 1	−111.1	−133.7	−175.5	−202.2	−231.1	−273 3	−306
α_γ	+ 9.1	+12.9	+15 5	+20 7	+24 7	+ 26 6	+ 27.4	+ 28.3	+ 28.7	+ 28.8	+ 28.8	+ 28.8

If we assume that the corpuscles come from a point in the XZ-plane, not at a distance 28.8, but at an infinite distance, we obtain a slightly different table, for if we employ the computations published in 1914 we find:

γ	− 0.1	−0 .2	−0 .3	− 0.4	− 0.5	− 0 6	− 0 7	− 0 8	− 0.85	− 0.9	− 0 92	−0.926	−0.9285	− 0 93
ψ_γ	+52°.0	+31°7	+20°5	+ 7°5	− 4°.5	−14°7	−20°4	− 14°1	− 2°1	− 15°.8	− 7°.9	− 7°.4	− 15°5	− 12°.6
ϕ_γ	−25.0	−28.3	−32 7	−38 7	−47.4	−60 9	−82.3	−114.5	−137 0	−179.5	−224.3	−253.5	−280.0	−310.1

On Plate I, *d* is seen a model of trajectories to the North Pole and South Pole, coming from points of emanation lying near each other. (Their distances from the origin are much less than in the models, Plate I, *b* and *c*.)

[15] See my Geneva paper of 1907, paragraph 19.

(*To be Continued.*)

NOTE CONCERNING THE EFFECT OF TERRESTRIAL RELIEF ON THE RATIO OF POSITIVE TO NEGATIVE IONIC DENSITIES IN THE ATMOSPHERE.

By P. L. Mercanton.

The slight inequality which is always found between the positive and negative ionic charge-densities in one and the same volume of air is considerably enhanced when observations are taken on an elevated point of the Earth's surface. Brunhes and Baldit[1] showed, as early as 1905, that at any rate up to 1500 meters altitude, the inequality results from a diminution in the negative ionic density rather than from an increase in the positive. All observers have noticed an enhancement of the ratio E_+ / E_- of the positive to the negative ionic charge-densities in the same mass of air. The ratio is identical with a_- / a_+, the ratio of the dispersion-coefficients, which is, in fact, the same thing as the ratio of the percentage rate of potential-diminution of a negatively charged body to that of a positively charged body under the same conditions, i.e.

$$\frac{E_+}{E_-} = \frac{\triangle V_-}{\triangle V_+}$$

Although the experiments here recorded date from 1906 and 1907, they are yet of considerable interest. The author has measured the ratio $\triangle V_- / \triangle V_+$ by means of an Ebert aspirating ion-counter, at the Tour de Gourze, near Lausanne. This tower is admirably suited for such experiments. It constitutes a regular Faraday cylinder, and stands at an altitude of 930 meters on an isolated hill exposed to the wind on all sides. The parapet overlooks the surrounding country from an altitude of about 10 meters above the soil. A single door in the eastern side gives access to the interior which is empty from top to bottom.

The series of measurements instituted by the author were made alternately at the foot of the tower, and on the top of it, that is to say first at a point of the interior where the electric field was zero, and then on the angle of the parapet, at a point where the electric gradient was a maximum. Special measurement gave zero field for the interior of the tower, while on the parapet the field attained a value as high as 1200 volts per meter.

The measurements of the dispersion concern those of the ions which Ebert's apparatus is capable of catching when it operates under a potential of some 150-240 volts, that is to say the most mobile of the ions. The results here given refer to a time interval of 15 minutes, and the time is Central European. The data obtained may be summarized as follows:

[1] *Journal de Physique*, ser. 4, vol. 5, p. 298, 1906.

October 9, 1906; weather perfectly fine; fresh S. S. W. breeze.

Interior of the tower; air calm; $13^h\ 45^m$ to $14^h\ 23^m$, $\frac{E+}{E-} = 1.57$.

Parapet, south angle; breeze; $14^h\ 42^m$ to $16^h\ 47^m$,

(two alternate series), $\frac{E+}{E-} = 4.33$.

Interior; air calm; $16^h\ 59^m$ to $17^h\ 34^m$, $\frac{E+}{E-} = 1.06$.

Hence we obtain for the mean value of $\frac{E+}{E-}$, 1.31 in the zero field, and 4.33 in the intense field.

October 12, 1906; weather fine for two days previously, and continued fair till the following day; a few clouds, principally on the summits of the Alps; air calm. The barometer fell on the 13th.

Parapet; $15^h\ 55^m$ to $17^h\ 20^m$, $\frac{E+}{E-} = 2.16$. (Intense field.)

Interior; $17^h\ 30^m$ to $18^h\ 3^m$, $\frac{E+}{E-} = 1.09$. (Zero field.)

October 24, 1906; weather fine; light mist on Lake Leman; a few cirrus clouds; broad sunshine; similar conditions on the preceding and following days; light breeze from the S. W.; dew at night. The soil of the inside of the tower was damp.

Interior; $12^h\ 33^m$ to $13^h\ 41^m$, $\frac{E+}{E-} = 0.73$. (Zero field.)

Parapet, south angle; $14^h\ 10^m$ to $14^h\ 43^m$, no positive dispersion. (Field = 1200 volts per meter.)

Parapet; $14^h\ 57^m$ to $16^h\ 5^m$, $\frac{E+}{E-} = 4.46$. (Intense field.)

Interior; $16^h\ 23^m$ to $17^h\ 13^m$, $\frac{E+}{E-} = 1.24$. (Zero field.)

Summing up, we see that: (1) in the terrestrial electric field the negative ions are in the minority and sometimes seem even to be entirely absent; (2) outside the field the ratio fluctuates about unity, the densities of the ions being sensibly the same. It might be expected that a violent wind would diminish the dissymetry. This is exactly what the following measurements, carried out under a violent and very cold wind from the N. E., showed. As the ground all around was covered with snow on that day, it may naturally be asked whether this circumstance did not affect the results.

February 5, 1907; occasional sunshine; fog high up.
Interior of the tower; gusts of wind coming in by the door blew up a small amount of powdery snow, lying inside the tower, into eddies; the instrument was held so as to be sheltered as much as

possible from these eddies; $13^h\ 22^m$ to $13^h\ 56^m$, $\frac{E_+}{E_-} = 1.08$. (Zero field.)

Parapet, S. W. angle, $\frac{E_+}{E_-} = 1.70$. (Intense field.)

Interior, $\frac{E_+}{E_-} = 1.30$. (Zero field.)

Thus, in the zero field the mean value of $\frac{E_+}{E_-}$ is 1.19, and in the intense field, 1.70.

We may note here a curious circumstance observed several times during the autumn of 1906, when the dispersion cylinder was charged positively. The dispersion was from time to time replaced by a recharging of the conductor, and on one occasion a rise of potential as great as 4.6 volts was obtained in 5 minutes. Generally, however, the rate of rise was less. These results are illustrated by the following potential measurements in volts per meter:

October 8, 1906. *Parapet;* charge on cylinder, positive; $16^h\ 27^m$, 220.2; $16^h\ 32^m$, 220.2; $16^h\ 37^m$, 220.2; $16^h\ 42^m$, 222.6; $16^h\ 47^m$, 221.4.

These observations were made only on the parapet, that is, in the intense field. Is this recharging effect real or only apparent? In the latter case one would be tempted to see the electric influence of some large and sluggish positive ions passing by without being caught by the dispersion cylinder in the current of air of the ion-counter.

Lausanne, Switzerland, 1916.

RESULTS OF MAGNETIC OBSERVATIONS AT SEDDIN, NEAR POTSDAM, RELATING TO THE SOLAR ECLIPSE OF AUGUST 21, 1914.

By Adolf Schmidt.

G. M. T.	North Comp. X	West Comp. $-Y$	Vert. Comp. Z	Hor. Comp. H	West Decl'n $-D$	G. M. T.	North Comp. X	West Comp. $-Y$	Vert. Comp. Z	Hor. Comp. H	West Decl'n $-D$
h m	γ	γ	γ	γ	° ′	h m	γ	γ	γ	γ	° ′
10 00	18562	2767	42884	18767	8 28.8	12 30	18586	2779	42887	18793	8 30.3
05	58	64	86	63	28.3	35	85	82	89	92	30.7
10	61	66	85	65	28.5	40	86	83	89	93	30.9
15	62	69	84	68	29.0	45	83	82	91	91	30.9
20	63	71	84	69	29.5	50	84	84	91	92	31.1
25	64	71	83	70	29.3	55	83	84	91	91	31.3
30	63	69	82	68	29.1	13 00	83	86	91	91	31.6
35	66	69	83	71	28.9	05	81	86	91	89	31.7
40	67	69	82	73	29.5	10	82	86	92	90	31.6
45	70	70	82	75	29.0	15	81	86	93	89	31.6
50	73	71	82	78	29.1	20	80	84	93	87	31.4
55	76	74	82	82	29.5	25	81	83	93	88	31.1
11 00	78	76	81	85	29.8	30	80	82	93	87	31.0
05	78	77	81	85	30.0	35	82	81	92	89	30.7
10	81	77	81	88	30.0	40	78	79	93	85	30.4
15	83	79	81	90	30.3	45	81	78	93	88	30.2
20	84	80	80	91	30.5	50	83	79	94	90	30.2
25	85	82	80	92	30.8	55	84	78	94	90	30.6
30	85	82	79	92	30.8	14 00	83	78	95	90	30.1
35	89	83	79	97	30.9	05	82	76	96	88	29.7
40	89	82	79	97	30.7	10	83	74	97	89	29.4
45	90	83	79	97	30.8	15	87	74	97	93	29.3
50	90	82	79	98	30.7	20	87	73	97	93	29.2
55	90	80	80	97	30.4	25	88	72	97	94	28.9
12 00	88	79	81	95	30.2	30	88	70	97	93	28.6
05	88	76	81	94	29.7	35	89	69	97	94	28.3
10	87	75	83	93	29.5	40	89	67	98	94	27.9
15	89	75	83	95	29.4	45	90	66	98	95	27.7
20	87	75	85	94	29.6	50	92	64	98	96	27.4
25	87	77	87	93	29.9	55	93	64	98	97	27.4
						15 00	93	64	99	97	26.9

[The above observations are not the results from special observations, but the five-minute values as derived from the usual magnetograms obtained at the Seddin Magnetic Observatory (latitude 52° 17′ N, longitude 13° 01′ E). Referring to Fig. 4, p. 82, *Terr. Mag.*, June, 1916, it will be found upon plotting the Seddin D-curve that the progression in the times when the marked bay occurred is confirmed by the Seddin curve, just as it was by the De Bilt curve, mentioned on p. 144 (*l. c.*, Sept., 1916). The lowest part of the bay for Seddin occurred at about $12^h\ 15^m$, or practically the same as at Rude Skov, as should be the case (see Figs. 1 and 2, *l. c.*, p. 59, June, 1916).—L. A. B.]

LETTERS TO EDITOR

DIURNAL AND ANNUAL VARIATION OF MAGNETIC BAYS AT ZIKAWEI, 1877-1908.

The Bulletin Magnétique de Zikawei has been publishing, since the service was transferred to Lukiapang, a summary of the perturbations which Dr. C. Chree has designated as *bays*, that is, those which consist in a single oscillation such that the curve resumes afterward approximately its former position, the bay being entirely on one side of what would have been the normal curve. It has seemed well to investigate such *bays* in the magnetograms obtained at Zikawei during the period March 1877 to March 1908.

I. *Diurnal variation.* The time is noted when the greatest departure of the bay from the normal position occurs. The number of such occurrences is determined for each hour of the day for the whole period; $0^h.5$ denotes the interval from 0^h to 1^h, civil time of Zikawei, etc. These numbers, reduced at first on the basis of 100 per hour, gave a mean, with reference to which the deviations or differences were taken, the latter being then smoothed by the method of the double mean. This work was done for the 31 years, 6 of which were of magnetic calm (1878, 1879, 1888, 1889, 1900 and 1901), and 6 of magnetic activity (1883, 1884, 1892, 1893, 1905 and 1906). Tables 1 and 2 and Fig. 1 represent these deviations.

TABLE 1.—*Diurnal Variation of Magnetic Bays at Zikawei.*

L. M. T.	31 Years	Calm Years	Active Years	L. M. T.	31 Years	Calm Years	Active Years	L. M. T.	31 Years	Calm Years	Active Years
h				h				h			
0.5	0.0	+0.8	+1.6	8.5	−2.8	−3.3	−3.4	16.5	−0.9	− 0.9	−0.2
1.5	−0.9	+0.1	−0.7	9.5	−3.4	−3.6	−3.2	17.5	+1.4	+ 2.5	+2.4
2.5	−0.9	−0.6	−2.3	10.5	−3.6	−3.8	−3.1	18.5	+6.3	+ 8.9	+6.0
3.5	−0.8	−1.1	−2.1	11.5	−3.8	−3.9	−3.5	19.5	**+9.1**	**+10.5**	+6.5
4.5	−1.7	−2.2	−2.7	12.5	*−3.8*	*−3.9*	*−3.7*	20.5	+8.3	+ 7.6	+6.4
5.5	−2.2	−2.6	−2.8	13.5	−3.5	*−3.9*	−3.3	21.5	+6.6	+ 5.4	+7.7
6.5	−1.9	−2.0	−2.3	14.5	−2.9	−3.8	−3.0	22.5	+4.1	+ 2.8	+6.2
7.5	−2.1	−2.3	−2.8	15.5	−2.0	−2.5	−1.9	23.5	+1.5	+ 0.9	+3.4

TABLE 2.—*Fourier Analysis of Diurnal Variation of Magnetic Bays at Zikawei.*

									°	°	°
A_1	+2.9	+3.0	+3.0	B_3	+0.4	−1.2	−0.1	α_1	141	139	143
A_2	−1.9	−1.9	−1.6	B_4	+0.7	+0.9	−0.2	α_2	226	230	220
A_3	−1.1	−0.8	−0.5	R_1	4.6	4.7	5.0	α_3	291	326	259
A_4	0.0	−0.7	+0.2	R_2	2.6	2.5	2.6	α_4	360	38	135
B_1	−3.5	−3.6	−4.0	R_3	1.1	1.4	0.5				
B_2	−1.8	−1.6	−2.0	R_4	0.7	1.1	0.3				

The two curves of Fig. 1 for the calm years and the active years, respectively, are almost identical. The daily range appears but slightly modified by solar activity; the maximum, however, seems to occur later during active years, but six years are not sufficient to prove this definitely.

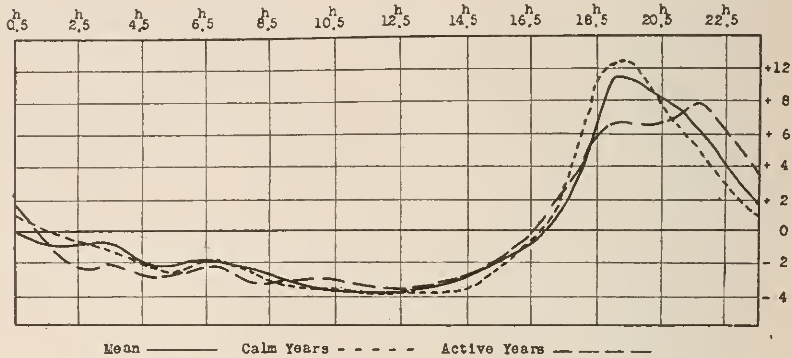


Fig. 1.

II. *Annual variation.* Mr. William Ellis has stated that perturbations are more numerous at the time of equinox than at the time of solstice. We desired to verify this assertion by limiting the investigation to a very special form of perturbation, namely, the *bays*. Accordingly the bays were grouped by months, and taking into account certain gaps, the monthly means, (Table 3; Fig. 2), were computed.

Table 3.—*Annual Variation of Magnetic Bays at Zikawei.*

January	4.2	April	2.6	July	2.2	October	4.3
February	**4.6**	May	2.0	August	2.8	November	3.8
March	2.8	June	*1.6*	September	**4.5**	December	3.5
						Mean for year	3.25

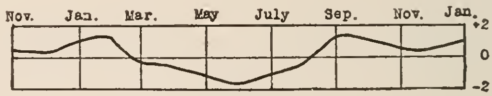


Fig. 2.

Mr. Ellis's statement is therefore sufficiently verified. Table 4 gives the results of the Fourier analysis.

Table 4.—*Fourier Analysis of Annual Variation of Magnetic Bays at Zikawei.*

$A_1 = +0.9$	$B_1 = -0.8$	$R_1 = 1.2$	$\alpha_1 = 132°$
$A_2 = -0.2$	$B_2 = +0.5$	$R_2 = 0.6$	$\alpha_2 = 345$
$A_3 = +0.3$	$B_3 = +0.3$	$R_3 = 0.4$	$\alpha_3 = 50$
$A_4 = +0.1$	$B_4 = +0.1$	$R_4 = 0.1$	$\alpha_4 = 45$

III. *Secular variation.* The quality of the photographs naturally varies greatly in 31 years. Moreover there are several gaps in them, especially in 1878, 1889 and 1901, which happen to be years of minimum activity. The sums for the various years can not be readily compared; however, they are given in Table 5. In order to have three cycles of eleven years, the years 1887 and 1897 were repeated.

TABLE 5.—*Secular Variation of Magnetic Bays at Zikawei.*

1877	10	1887	**52**	1897	**92**
78	13	*88*	80	98	55
79	*9*	*89*	*28*	99	54
80	23	90	38	*1900*	18
81	26	91	49	*01*	*13*
82	39	**92**	59	02	*13*
83	28	**93**	49	03	31
84	23	94	44	04	32
85	43	95	61	**05**	29
86	47	96	71	**06**	20
87	**52**	97	**92**	07	32

The three minima correspond sufficiently well with the epochs of solar calm. This is not, however, the case with the maxima, nor with the large number in 1888. It would therefore be presumptuous to draw any definite conclusion at present respecting correspondence in the secular variation of magnetic bays with changes in solar activity during Sunspot cycle.

MARCHE DIURNE DES ÉLÉMENTS MAGNÉTIQUES À ZIKAWEI.

Le Dr. C. Chree vient de publier (The seventh Kelvin Lecture in the Journal of the Institution of Electrical Engineers, vol. 54, p. 410 et seq.) une comparaison très intéressante de la marche diurne des éléments magnétiques à Kew et dans l'Antarctique. Pour Kew il a pris onze ans et pour la station polaire les 22 mois dont il disposait. Les analogies et les différences sont frappantes. M. Chree examine aussi les jours calmes (5 par mois à Kew et 10 dans l'Antarctique) et les jours troublés (5 par mois).

Il se trouve que depuis 1909 nous donnons aussi dans nos Bulletins, mois par mois, la marche diurne pour tous les jours, pour 5 jours calmes et pour 5 jours troublés. La vue des graphiques du Dr. C. Chree a fait espérer qu' en groupant, saison par saison, pour 4 ans, on trouverait peut-être aussi un résultat. Le calcul a été conduit le plus possible comme à Kew. L' heure notée est l' heure de la Côte de Chine, c'est-à-dire que 8^h correspond à minuit de Greenwich.

Nos graphiques (Fig. 3 et 4) appellent quelques remarques.

1. Ils sont beaucoup moins réguliers et surtout moins circulaires que ceux du Dr. C. Chree. En été, l' amplitude de la variation de X est beaucoup plus faible que celle de Y. Cette particularité viendrait-elle de la latitude de notre station? L' amplitude, très grande à l'Antarctique,

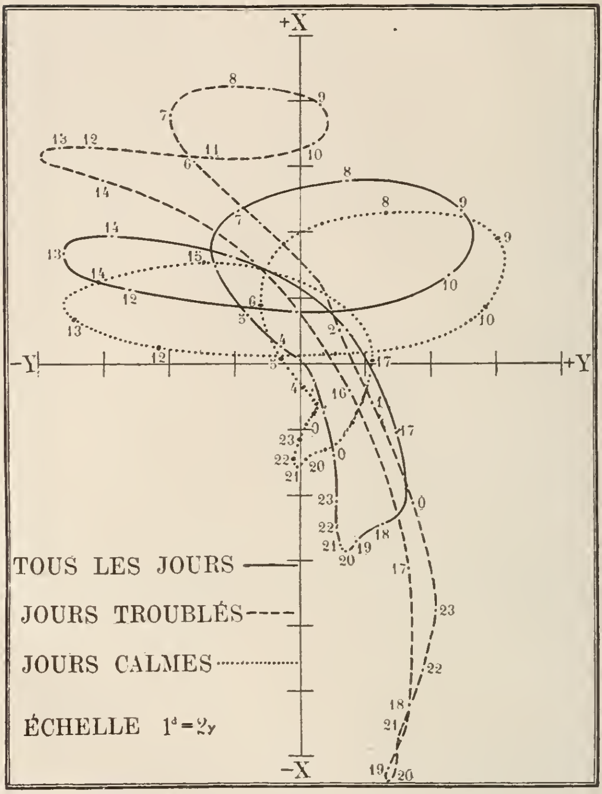


FIG. 3.—MARCHE DIURNE, HIVER, 1909-1912.

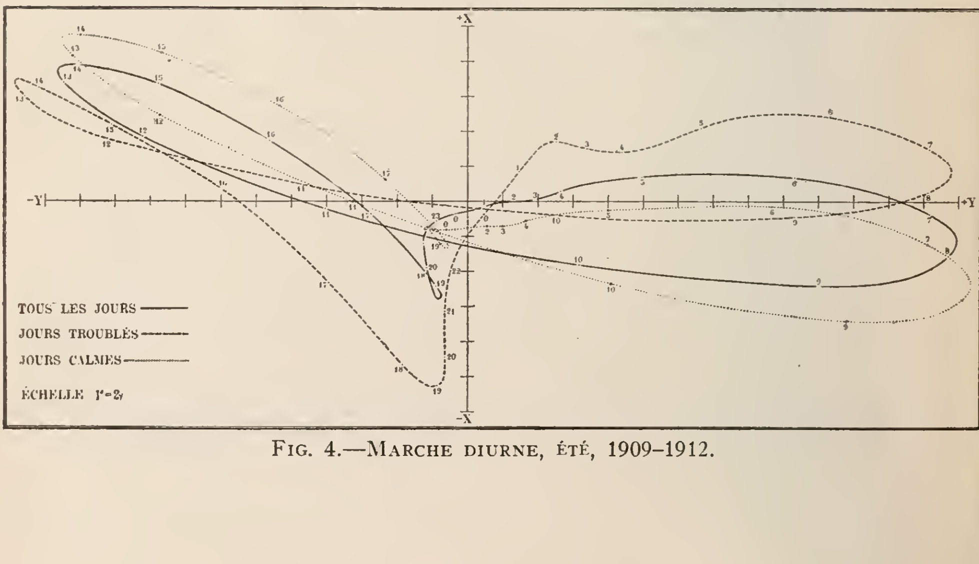


FIG. 4.—MARCHE DIURNE, ÉTÉ, 1909–1912.

est plus petite à Kew (51°) et encore plus petite ici (31°). Il y aurait à voir si elle est encore moindre près de l'équateur magnétique. La différence des saisons est peut-être encore plus notable. Comme partout, les courbes sont plus grandes en été, plus petites en hiver. Mais chez nous la courbe d' hiver n' a presque plus aucune régularité, surtout la nuit.

2. La marche relative aux jours troublés et en toute saison celle de la nuit, est bien plus irrégulière que d'après la courbe de onze ans à Kew. Cela se comprend assez et disparaîtrait sans doute ou serait fort atténué, si nous combinions onze ans ou plus. Mais il est assurément bien curieux qu'au pôle sud, où les aimants sont considérablement plus agités qu'à nos latitudes, quelques mois aient suffi à donner un tracé bien plus régulier et presque circulaire.

3. Non seulement la grandeur du graphique diffère ici selon les mois, comme on peut le voir dans nos Bulletins, mais la forme aussi varie. De telle sorte qu'une combinaison des 12 mois, que nous avons tentée, donne une allure totalement factice, qui ne convient en réalité à aucune saison de l' année.

VARIATION ANNUELLE DE LA DÉCLINAISON MAGNÉTIQUE À ZIKAWEI, 1877-1908.

La marche annuelle de la déclinaison n'est pas manifeste comme la variation diurne, qui est évidente et depuis longtemps étudiée; elle est petite et facilement voilée par des mouvements accidentels. La revue que nous avons faite des 31 ans pendant lesquels un enregistreur Adie a fonctionné à Zikawei, a fourni quelques remarques à ce sujet. Nous les donnerons en quelque détail, non que tous les points que nous toucherons soient bien démontrés, mais parce que l'ensemble, croyons-nous, ne laisse guère de doute sur la réalité de l'inégalité, sur sa grandeur qui est ici d'environ 20 secondes, et sur l'époque de ses élongations, qui ont lieu vers les équinoxes.

Les 31 ans ont fourni trois cycles, dont deux n'ont que dix ans: 1877-1886 et 1887-1896, et un qui est complet: 1897-1908. On a d'abord effectué une petite correction, de mars 1877 à mai 1878, et de novembre 1878 à décembre 1889. Elle revenait à multiplier D par 0.9603.

Trois mois manquaient, février 1889, juin 1894, décembre 1901. Une première approximation ayant montré qu'à ces époques de l'année ne se présente ni maximum ni minimum, on a pris pour ces trois mois la demi-somme du mois précédent et du suivant. Juin et juillet 1895 manquaient également: on a interpolé graphiquement, l'autre procédé ne donnant rien de satisfaisant.

Ayant ainsi toutes les moyennes mensuelles, on en a fait les sommes pour chaque cycle et pour l'ensemble des 31 ans, en donnant à chaque année le même poids, ce qui n'est pas tout à fait juste. On a fait aussi les mêmes sommes pour 6 années calmes, 1878-79, 1888-89 et 1900-01, ainsi que pour 6 années actives, 1883-84, 1892-93 et 1905-06. La variation non-cyclique était fournie pour chaque série par le janvier suivant, pour la dernière par janvier 1908. Les deux mois de 1908 n'ont pas été utilisés autrement.

Si on compare les différents tracés, il est difficile de dire, à moins de se contenter d'un à peu près assez grossier, que la courbe de tous les jours est *entre* celle des années calmes et celle des années actives. Il ne serait pas sans intérêt de savoir s'il en est de même à d'autres stations, par exemple, à une station équatoriale et à une station de latitude plus élevée que la nôtre.

D'après le troisième cycle, qui seul est complet, et d'après la série de 31 ans, le minimum se présente à l'équinoxe du printemps et le maximum vers le 10 septembre. Les passages par la moyenne, qui sont moins fixes, se présentent du 20 mai au 20 juin et du 1 novembre au 1 décembre, soit avant les solstices.

L'amplitude des quatre groupes serait 0'.270 0'.460 0'.430 0'.365 ou environ 22".

Si on considère maintenant les deux autres groupements, on est surpris de trouver pour les deux une amplitude plus grande que celle de l'ensemble, 0'.579 pour les années calmes et 0'.827 pour les années actives. Pour les deux, l'élongation orientale ou minimum est vers la fin de mars, à l'équinoxe encore. L'élongation occidentale est un peu après l'équinoxe d'automne pour les années calmes; mais elle est moins bien déterminée que pour nos 6 années actives, pour lesquelles elle aurait lieu vers le 1 septembre. Les zéros auraient lieu vers le 1 juin et dans la seconde moitié de novembre. Les deux courbes sont absolument du même type, pendant le premier semestre, mais elles diffèrent ensuite assez notablement. Ce n'est, je crois, là qu'une apparence venant de ce que nos moyennes ne sont déterminées que par six ans. Or en 1878, la valeur de septembre est très petite, 1'.70 plus petite que celle d'octobre. Comme par ailleurs, en l'été de cette année-là, les mesures n'ont pas été faites de la même manière. Les deux courbes pourraient fort bien avoir le même galbe toute l'année.

EFFET DE LA POSITION DE LA LUNE EN ANGLE HORAIRE SUR LA DÉCLINAISON MAGNÉTIQUE À ZIKAWEI.

Les notes suivantes sont relatives à l'effet qu'a sur la déclinaison magnétique la position de la Lune en angle horaire. Pour cette étude, nous avons utilisé un tableau, où est donné l'angle horaire de la Lune, tous les jours, à midi moyen de Zikawei pour une trentaine d'années; c'est dire que nous n'avons utilisé qu'une observation magnétique par jour. Nous nous sommes même limités à une période de onze ans et deux mois, de janvier 1890 à mars 1901. De la sorte nous prenions la Lune à 15 heures d'angle horaire et nous la laissions aussi à 15 heures. C'était du reste une période solaire. La valeur observée de D pour chaque jour était attribuée à l'angle horaire occupé alors par la Lune. Le cercle céleste était divisé en zones de 15 degrés que nous appellerons heures lunaires pour abréger.

Pour valeur observée, on prenait la différence entre la valeur de midi et la moyenne du jour. De plus, pour éliminer la marche annuelle ou séculaire due au Soleil, on retranchait, tous les jours de chaque mois,

la différence entre la moyenne de midi et la moyenne mensuelle proprement dite.

Exemple. 1 Janvier 1890.

	° ′		° ′
Déclinaison à midi:	2 13.29	Moyenne de midi, janvier 1890:	2 11.89
Moyenne du jour:	2 11.93	Moyenne de janvier 1890:	2 11.45
Différence:	+ 1.36	Valeur à retrancher:	0.44
À retrancher:	0.44		
Valeur dite observée:	+ 0.92		

Ce jour-là, à midi moyen de Zikawei, l'angle horaire de la Lune était $15^h\ 47^m$. La valeur trouvée a donc été attribuée à 15^h. Il n'a pas été fait de correction pour la variation non-cyclique.

Les moyennes obtenues correspondaient aux demi-heures lunaires; pour les ramener aux heures justes, c'est-à-dire à 0°, 15°, 30°, etc., on a fait les demi-sommes de deux moyennes consécutives; ainsi pour 1^h on a toutes les observations de midi entre 0^h et $1^h\ 59^m$ d'angle horaire.

On a calculé à trois décimales, sans assurer, bien entendu, le millième de minute. Les valeurs obtenues et le tracé représentatif (fig. 6) sont donnés plus bas. Sur ce dernier on remarquera que le maximum se présente très peu après 0^h et quelque peu avant 12^h, c'est-à-dire au passage de la Lune par le méridien, avec des valeurs sensiblement égales. Le minimum est double aussi: à 6^h et à 18^h, mais avec des valeurs bien inégales. Ce dernier point n'est pas dû à une année en particulier mais un grand nombre de fois le minimum de 18^h est beaucoup plus bas que celui de 6^h.

II.

Cette action lunaire étant notable, puisque elle dépasse une demiminute, son allure varie-t-elle avec la position de notre satellite sur son orbite?

On a étendu la première étude à un saros, c'est-à-dire de 1890 à la fin du service à Zikawei en mars 1908.

On a ensuite plus spécialement examiné la déclinaison de la Lune. À chacune des dates où la Lune a sa déclinaison maximum, i. e. boréale, ou minimum, i. e. australe, on a pris cinq jours, car aux environs des valeurs extrêmes la déclinaison varie fort lentement. Parmi les valeurs de *D* employées précédemment pour la période de onze ans on a attribué celles qu'on avait choisies aux heures lunaires définies comme ci-dessus. Chaque année suffisait à donner une valeur à chacune des 24 heures lunaires, en commençant vers 14^h pour les déclinaisons boréales et vers 1^h pour les déclinaisons australes. On a donc omis les deux mois de 1901, pour que chacune des heures fût déterminée de la même façon. Dans l'ensemble, la valeur de chaque heure était la moyenne d'un nombre de données variant de 25 à 33. Ceci était beaucoup moins bon que dans le premier calcul où ces nombres allaient de 154 à 182, et que dans celui du saros où ils allaient de 257 à 284. On se contenta donc de deux décimales comme plus que suffisantes.

Pour les deux groupes de six ans, nous avons préféré nous servir de cette remarque que, dans l'ensemble, décembre diffère très peu de janvier.

La correction non-cyclique une fois effectuée, on a calculé les moyennes, puis les écarts qui ont enfin été adoucis par double moyenne. Voici ces écarts (Tableau 6). Les chiffres se rapportent au milieu de chaque mois.

Tableau 6.

Mois	Premier cycle	Deuxième cycle	Troisième cycle	Les 31 ans	Années calmes	Années actives
	′	′	′	′	′	′
Janvier	−0.005	+0.039	−0.093	−0.022	−0.218	−0.175
Février	−0.068	−0.084	−0.134	−0.097	−0.253	−0.280
Mars	−0.101	−0.178	*−0.202*	*−0.162*	*−0.301*	*−0.368*
Avril	−0.114	*−0.180*	−0.167	−0.155	−0.255	−0.312
Mai	*−0.151*	−0.163	−0.034	−0.114	−0.046	−0.186
Juin	−0.066	−0.137	+0.098	−0.031	+0.188	+0.026
Juillet	+0.085	−0.063	+0.170	+0.067	+0.244	+0.301
Août	**+0.119**	+0.113	+0.220	+0.152	+0.197	**+0.459**
Septembre	+0.100	**+0.281**	**+0.227**	**+0.203**	+0.251	+0.436
Octobre	**+0.119**	+0.226	+0.100	+0.146	**+0.278**	+0.216
Novembre	+0.074	+0.083	−0.066	+0.027	+0.072	−0.008
Décembre	+0.011	+0.063	−0.116	−0.017	−0.152	−0.109
Janvier	−0.005	+0.039	−0.093	−0.022	−0.218	−0.175

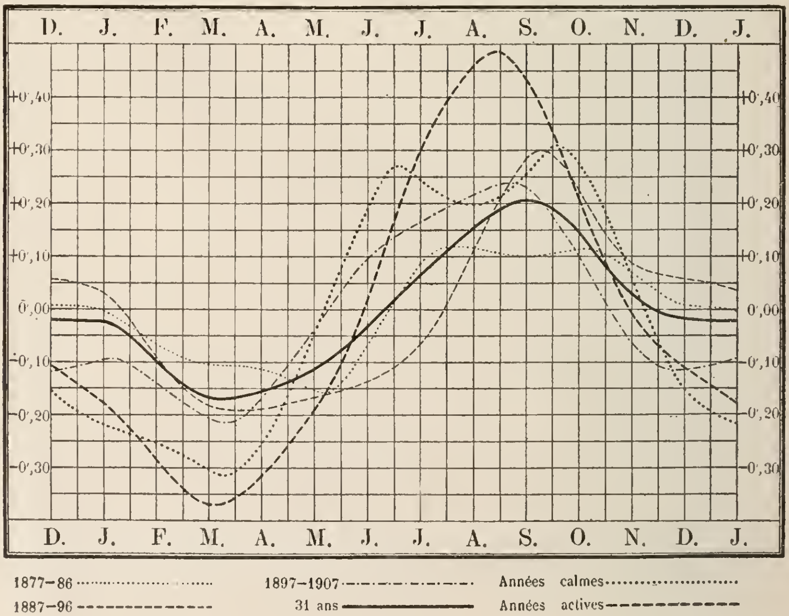


Fig. 5.

Enfin on prit le cas des noeuds, mais à chaque noeud ascendant ou descendant, la variation de la déclinaison étant rapide, on ne prit que trois jours. On n'a pas groupé à part les deux espèces de noeuds. De la sorte on a eu à peine un peu plus de cas: de 28 à 41 par heure.

Le même calcul, essayé d' abord, soit par un procédé différent, soit pour un plus petit nombre d'années, n'a pas à être reproduit ici; mais il nous a confirmé dans la pensée que l'inégalité dont il est question a bien une réalité objective.

III.

Le cas du saros, plus général, paraît représenter le mieux le phénomène. Le graphique est plus adouci, plus régulier et un peu plus ample que celui du cycle solaire. Il s'en rapproche du reste beaucoup, les heures qui diffèrent le plus dans les deux séries s'écartent en effet au plus de 3″. L'analyse harmonique, pour ce cas de 18 ans, donne, en prenant la forme: $y = M + R \sin (a - x) + \ldots$

$$\begin{array}{lll} \alpha_1 = 359^\circ & \quad & R_1 = 0'.031 \\ \alpha_2 = 87 & & R_2 = 0.248 \\ \alpha_3 = 139 & & R_3 = 0.018 \\ \alpha_4 = 109 & & R_4 = 0.033 \end{array}$$

Tableau 7.

Heure	Saros	Onze ans	Nord	Sud	Noeuds
h	′	′	′	′	′
0	**+0.282**	**+0.282**	+0.49	−0.06	**+0.45**
1	+0.242	+0.251	**+0.54**	*−0.21*	+0.31
2	+0.109	+0.102	+0.33	*−0.21*	+0.08
3	−0.008	−0.015	+0.18	−0.18	+0.04
4	−0.105	−0.096	−0.11	−0.14	−0.15
5	−0.154	*−0.139*	*−0.33*	−0.01	*−0.29*
6	*−0.177*	−0.138	−0.24	+0.04	−0.27
7	−0.157	−0.115	−0.10	−0.04	−0.14
8	−0.115	−0.072	−0.01	−0.01	−0.02
9	−0.040	−0.014	+0.19	−0.00	−0.13
10	+0.106	+0.132	**+0.36**	+0.27	−0.01
11	+0.240	**+0.272**	+0.22	**+0.56**	+0.29
12	**+0.257**	+0.217	−0.07	+0.40	**+0.33**
13	+0.219	+0.162	−0.18	+0.36	+0.27
14	+0.124	+0.097	−0.11	+0.28	+0.07
15	−0.042	−0.050	−0.06	+0.04	*−0.23*
16	−0.127	−0.117	−0.10	−0.09	−0.22
17	−0.189	−0.214	−0.27	−0.27	−0.17
18	*−0.287*	*−0.324*	−0.42	*−0.42*	−0.20
19	−0.266	−0.265	*−0.48*	−0.33	−0.16
20	−0.182	−0.180	−0.30	−0.20	−0.18
21	−0.081	−0.093	−0.03	−0.14	−0.13
22	+0.116	−0.099	+0.17	+0.06	+0.07
23	+0.237	−0.220	+0.31	**+0.13**	+0.27

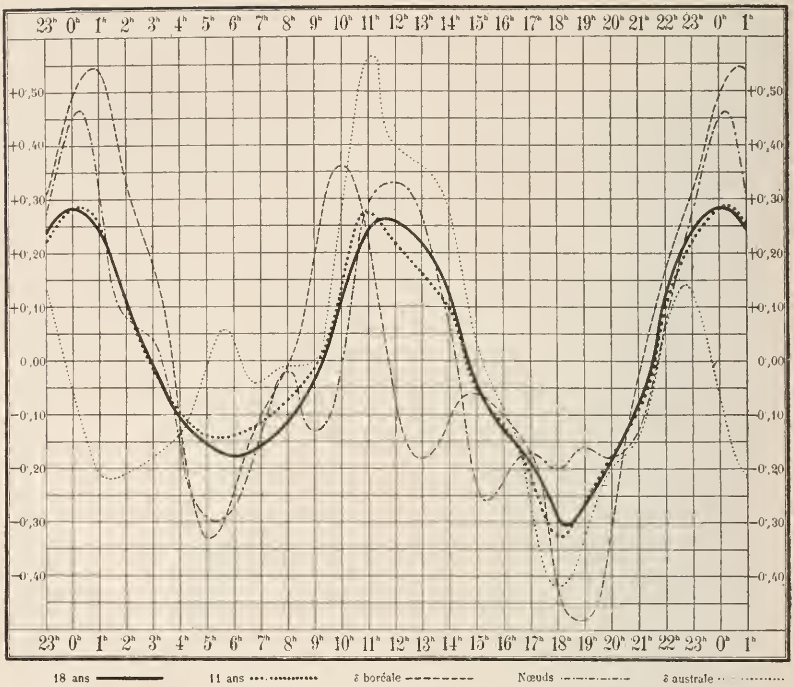


Fig. 6.

Les moyennes M sont dans tous les cas fort petites : pour le saros $+0'.002$, pour les onze ans $+0'.003$, pour les déclinaisons boréales $-0'.087$, pour les déclinaisons australes $-0'.113$ et pour les noeuds $+0'.135$. Voici maintenant la liste des écarts (Tableau 7).

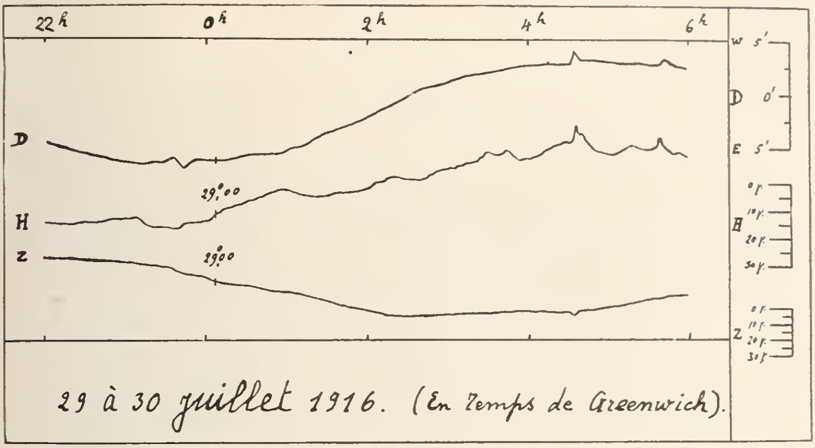
ÉCLIPSE ANNULAIRE DU 30 JUILLET 1916, À. ZIKAWEI

Bien que l'éclipse ne fût pas totale, voici la copie de nos courbes et ce que nous ont donné les mesures absolues. On les a faites ainsi que deux graduations avant et après l'éclipse. D'où valeur du millimètre pendant l'éclipse :

$$dD = 0'.48 \qquad dH = 1.88\gamma \qquad dZ = 3.03\gamma$$

		h m	° ′		h m	° ′
D	28 juillet	23 15	3 12.31	1 août	0 30	3 11.18
	29 "	6 22	3 18.47	"	6 59	3 18.36
I	29 juillet	8 52	45 32.5	1 août	8 40	45 30.3
H	29 juillet	0 32	33192γ	1 août	9 33	33211γ

Une marque a été faite le 30 à $0^h\ 7^m$. Nous notons le temps de Greenwich.



29 à 30 juillet 1916. (En Temps de Greenwich).

FIG. 7.

Les courbes étaient très calmes avant l'éclipse. On note une fort légère agitation vers le début, puis le calme se rétablit. À 4^h 33^m paraît ce que nous appelons crochet isolé, mais d'une grandeur quelque peu inusitée. Puis le calme reprend.

J. DE MOIDREY, S.J.

NOTES

1. Principal Magnetic Storms Recorded at the Cheltenham Magnetic Observatory, October-December, 1916. The following data have been communicated by the Superintendent of the United States Coast and Geodetic Survey:

Latitude 38° 44′.0 N; longitude 76° 50′.5, or $5^h\ 07^m.4$ W. of Greenwich.

Greenwich Mean Time		Range		
Beginning 1916	Ending 1916	D (Declination)	H (Hor'l Int.)	Z (Vert'l Int.)
h m	h	′	γ	γ
Oct. 5, 20 08	Oct. 9, 10	49.7	201	169

2. *Personalia. Lady Rucker* informs us that she has for disposal at a fair price a set of the *Annalen der Physik*, 1824-1914 and of the *Beiblätter*, 1877-1914, belonging to the library of the late lamented Sir Arthur Rucker; her address is Everington House, Newbury, Berkshire, England.

3. The magnetic-survey vessel, the *Carnegie*, under the command of J. P. Ault, arrived at Buenos Aires, with all well on board, on March 2. Leaving San Francisco on November 1, 1916, she proceeded to Easter Island, thence around the Horn to Buenos Aires. The scientific work was successfully accomplished on the entire trip.

4. *Corrigendum.* In some of the copies of the December 1916 number of the Journal, the Notes, page 208, were omitted. Those who received defective copies should inform the Editor as promptly as possible.

ABSTRACTS

ULJANIN, W.—*An Electrical Method of Measuring the Horizontal Component of the Earth's Magnetic Field.*[1]

The method is that of the sine galvanometer. The intensity of the current which passes through it is measured by compensation with a normal Weston cell through a given resistance. The galvanometer is provided with a second pair of coils which act on the same magnet and which, introduced into the circuit of the normal cell, serve to show there the absence of current. This arrangement is very convenient and renders unnecessary the use of a second galvanometer. The constant factor of the sine galvanometer may be measured by comparison with another instrument of which the constant is known, or deduced from simultaneous measurements of the horizontal component made by means of a magnetometer. Several series of measurements made at the University of Kazan together with the values of H furnished by an intensity variometer have been utilized in determining the constant of the galvanometer. Its constancy proves that the galvanometer-method is such as to give the value of the horizontal intensity with a precision at least equal to that given by the magnetometer-method. In view of the ease and the rapidity of measuring H by means of the galvanometer (it requires not more than 15 minutes), this method deserves to replace in practice the classic Gauss-Lamont method.

The last chapter contains the description of a small induction-coil turning in the interior of a long coil traversed by a current, which offsets the component of the magnetic field directed along the axis of this coil and of which the intensity is measured by compensation. This apparatus can also serve for measuring the vertical intensity.

STARLING, S. G.—*The Equilibrium of the Magnetic Compass in Aeroplanes.*[2]

This paper explains the existence of a deviation peculiar to the aeroplane. It is a dynamic deviation of the compass (i.e., it is produced by motion of the craft, compass, etc.), but differs from the dynamic deviation of ships at sea heretofore investigated, in that it is caused by changes of the aeroplane's progressive rectilinear motion. For example, small deviations may be caused by the dipping of the card. The card dips with accelerated or retarded motion of the aeroplane even when flying in a straight line because the center of gravity of the card is below the center of suspension. Theoretically, deviations due to changes in rectilinear

[1] Translated from "Méthode électrique pour la mesure de la composante horizontale du champ magnétique terrestre" par W. ULJANIN. Pétrograd, K. Birkenfeld. 1915.

[2] *Phil. Mag.*, London, vol. 32, November, 1916 (461-476).

motion exist also for ships at sea. But a ship at sea usually progresses with uniform speed in straight lines; at other times when the changes are made in speed or direction they are so small that any deviations in the compass caused thereby are negligible in practical navigation.

In an aeroplane, however, according to Starling, the greatest deviations occur when the aeroplane is making a turn. When the aeroplane is turning, it is tilted towards the center of the circle it is describing. The tilt becomes greater as the speed is increased or the radius decreased. Everything movable which was at rest in the aeroplane during straight-line uniform flight under the action of gravity alone is still at rest relative to the aeroplane as it tilts on the turn, but now, everything is at rest under the action of the resultant of gravity and centrifugal accelerations. The compass card, which was horizontal during rectilinear flight, is now tilted with the aeroplane and consequently partly turned in the Earth's magnetic field. The vertical component of the Earth's field, which was normal to the card in its level position in rectilinear flight and which consequently had then no directive effect, now has a component in the plane of the card and normal to the magnetic axis which tends to produce the deviation. The Earth's horizontal component also plays a part in this deviation.

These deviations are peculiar in that they occur only when the aeroplane is turning. Their magnitude depends upon the tilt of the aeroplane, the magnetic dip, and the heading or course. When the angle of tilt approaches the complement of the magnetic dip, the deviations may increase to nearly 90 degrees on an easterly course (in northern hemisphere), and when it exceeds the complement, the compass will be completely reversed on an easterly heading.

Means of adjustable compensation are suggested in the paper. Although the deviations produced by turning may be very large, yet they disappear on resuming straight flight. When the aeroplane travels over unknown country, in reconnaissance work, in night flight, etc., it probably travels in straight lines during most of its flight. It would therefore appear that the introduction of movable compensating devices, designed to correct fleeting deviations, would be dangerous in the liability to produce magnetic deviations of a more permanent character, even though they might be small. If they are used, there should be some control over their effectiveness.

The theory of deviations produced by the turning of an aeroplane assumes a compass card balanced without unsymmetrical distribution of weight. Such a balance might be secured, sufficient for practical purposes, by making the position of the center of gravity very low. A loaded compass-needle, as for example, the commercial compass-needle, would introduce further complications in the problem, since it is usually weighted and the center of gravity is not far below the center of suspension.

W. J. Peters.

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A. Terrestrial and Cosmical Magnetism.

Agincourt Observatory. Magnetic observations, August, 1916. Toronto, J. R. Astr. Soc. Can., v. 10, No. 9, Nov., 1916 (507-508).

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Arctowski, H. Positions héliographiques des taches solaires et orages magnétiques. Paris, C.-R. Acad. sci., T. 164, No. 3, 15 janvier 1917 (145-147).

Argentina. Ministerio de Marina. Anales hidrográficos. Tomo I. Buenos Aires, Ministerio de Marina, Secretaria General, División de Hidrografia, Faros y Balizas, 1915 (vi + 388 con figs.). 25 cm. [Contains absolute values of magnetic declination and horizontal intensity made during January, February, and March, 1912, at Montevideo, Pilar and Colonia, also instructions for use of Brunner field instruments and declination and horizontal-intensity values at Isla de Año Nuevo Observatory during 1902 to 1906, inclusive.]

Belot, É. Tracé provisoire de la courbe décrite par le Pôle magnétique boréal depuis 1541. Paris, C.-R. Acad. sci., T. 164, No. 2, 8 janvier 1917 (113-116).

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Terrestrial Magnetism
and
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MAGNETIC "ACTIVITY" AND HOURLY RANGES.

By C. Chree.

§1. An international scheme has been in operation for some ten years, whose object is to discriminate between days according to the greater or less amount of magnetic disturbance. At all cooperating stations each day has allotted to it the "character" figure 0, 1 or 2, according as it is quiet, moderately disturbed, or highly disturbed. The figures thus arrived at are communicated to the Directoı of the Netherlands Meteorological Institute at De Bilt, who publishes full details quarterly. Finally at the year's end he assigns to each day a "character" figure, representing the mean estimate of the cooperating stations, omitting those whose returns are insufficiently complete. Supposing as many stations to assign a 0 as a 1 to a particular day, the finally accepted figure for the day is 0.5. These final figures are given to 0.1 in the De Bilt lists. The scheme is so far satisfactory. A high "character" figure always connotes more than usual disturbance, a low figure a general absence of disturbance. But the *amount of disturbance* on different days, even days of the same month, bears no ascertainable relation to the numerical values of the corresponding "character" figures. Two days, especially days in different months or different years, may be assigned the same "character" figure, while differing widely in disturbance. In short, the international "character" figure has more the semblance than the reality of a quantitative measure. Thus the existing scheme, useful as it has proved, is not altogether ideal.

One obvious preliminary to an exact numerical measure of disturbance is a precise definition. It is, however, doubtful whether an absolute distinction can be made between what is normal or quiet and what is disturbed. If we take a large number of days which are conspicuously disturbed, we derive from hourly measurements a regular diurnal inequality which is not the same as that

derived from quiet days. This difference seems specially conspicuous in high latitudes. At the station of the last Scott Antarctic Expedition the diurnal inequality from the 5 most disturbed days of each month of the years 1911 and 1912 was just as regular as that derived from the 5 international quiet days of each month, but had a range three or four times as large. Thus the regular forces are not the same on days of large and on days of small disturbance. Disturbance does not mean merely superposing irregular movements on the regular movements characteristic of quiet days.

§2. A scheme of a different kind was proposed some years ago by the late Prof. Bidlingmaier,[1] then attached to the Wilhelmshaven observatory. It aimed at distinguishing between days by securing an estimate of the energy which goes to produce all the magnetic changes of the day, regular and irregular. If α, β, γ denote rectangular components of magnetic force at a point x, y, z, the energy of the field is given by the integral

$$(1/8\pi) \int\int\int (\alpha^2+\beta^2+\gamma^2)\ dx\, dy\, dz$$

Suppose now that α, β, γ represent not the absolute values of the magnetic elements, but their departures from the normal, the integral may then be regarded as a measure of the energy of the forces which cause the field at each point to depart from its normal value. Professor Bidlingmaier aimed at getting the mean value of this quantity for each day.

Let $y_1 \ . \ . \ . \ y_{24}$ be the departures, from a certain fixed or normal value, of the 24 mean hourly values of a magnetic element, y_1 corresponding to the interval 1^h to 2^h, and so on. Let $y_n+\eta$ be the departure at any instant between hours n-1 and n, and let τ represent one hour of time. As y_n is the mean for the hour

$$\int_{(n-1)\tau}^{n\tau} (y_n+\eta)^2\, dt = \tau\, y_n{}^2 + \int_{(n-1)\tau}^{n\tau} \eta^2\, dt = \tau\,(y_n{}^2 + I_n), \text{ say.}$$

Similarly

$$\int_0^{24\tau} y^2\, dt = \tau\,(y_1^2 + \dots + y_{24}^2) + \tau\,(I_1 + \dots + I_{24})$$

For the mean value of the energy integral throughout the day, we have

$$(1/8\pi)\ (1/24\tau) \int_0^{24\tau} y^2\, dt = A_1 + A_2)$$

[1] Veröffentlichungen des Kaiserlichen Observatoriums in Wilhelmshaven; Ergebnisse der magnetischen Beobachtungen im Jahr 1911.

where

$A_1 = (1/8\pi)(y_1^2 + \ldots + y_{24}^2)/24$, and $A_2 = (1/8\pi)(I_1 + \ldots + I_{24})/24$.

If the normal value be the mean value for the day, y_1, y_2, etc., are the successive hourly terms in the diurnal inequality. If our object were to compare not days, but years, the natural normal would be the mean value for the year. But even the mean yearly value alters through secular change, and if we were comparing one group of years with another we should have to go a step further. Thus an absolutely complete treatment of the problem on Bidlingmaier's lines would be extremely complicated. It would require knowledge fully available only years after the event. For the immediate purpose of comparing one day with another, Bidlingmaier accepted for the normal value the mean value of the individual day. It cannot be claimed that this is altogether satisfactory. Take, for instance, the case of H, the horizontal intensity, for the two days immediately following a large magnetic storm. The difference between the mean value for the day and the mean value for the month or year may be 100γ on the first day, and only 10γ on the second. Thus the former day would contribute immensely more than the second to $(1/365)\,\Sigma(\bar{y} - Y)^2$, where $\bar{y}$ and Y are, respectively, the mean values for the day and the year. If we treat each day as a separate unit, such differences as this are disregarded. Accepting the mean value for the day as the normal, A_1, A_2 and $A_1 + A_2$ are equivalent to Bidlingmaier's $A^h_{d,24}$, $A^x_{h,24}$ and $A^x_{d,24}$, the letter A representing "Activity" ("Erdmagnetische Aktivität").

For comparative purposes, the retention or omission of the factor $(1/8\pi)$ is immaterial. If it is retained, and the quantities y_1 etc. are expressed in terms of 1γ (or 1×10^{-5} C. G. S.), then $A_1 + A_2$ represents, in terms of $1\epsilon = 1\times10^{-10}$ erg, the average amount of energy throughout the day per cm.³ of the field (counted from the normal as zero) at the given station.

Magnetic curves are usually measured in the first instance in mm., and Bidlingmaier applied his calculations to curves so measured, and only at the final stage did he express the results in terms of ϵ, by applying the factor $(1/8\pi)$ (sensitiveness)^2, where sensitiveness = equivalent in γ of 1 mm. of curve ordinate. Suppose, for instance, the sensitiveness is 5γ per mm., then the factor is $(25/25.13) = 0.995$, or practically 1.

The calculation of A_1 presents no difficulty, supposing the mean hourly values known. One point, however, should be noticed.

y_1, for instance, is supposed by Bidlingmaier to be the mean value for the hour ending at 1^h, whereas the general practice, at least in England, is either to measure the curve, smoothed or unsmoothed, at exact hours, or else to estimate the mean value for 60 minutes centering at the hour. So far as I am aware, the method of measuring the curves postulated by Bidlingmaier is practised at only a few observatories, including Potsdam and Seddin. The Potsdam method may eventually come into general use, but at present opinions differ as to its relative advantages and disadvantages. It is thus an important question whether hourly measurements as ordinarily made, suffice for the calculation of A_1. The answer to the question seems to depend on whether the practice is to read the unsmoothed curve at the hour, or to obtain the mean value for 60 minutes. In the former event a second set of readings would seem to be absolutely necessary, except perhaps on quiet days. In the latter event, if the hourly values from 0^h to 24^h are $y_0 \ldots y_{24}$, then it would probably be found satisfactory in practice to take

$$A_1 = (1/8\pi) \left\{ \tfrac{1}{2} (y_0^2 + y_{24}^2) + y_1^2 + \ldots + y_{23}^2 \right\} /24$$

At the same time, it must be allowed that the "activity" found from the above formula for a particular day would occasionally be sensibly influenced by a large movement which occurred during the last half-hour of the previous day, or the first half-hour of the subsequent day.

§3. To find A_2 implies, in any case, measurements additional to those now taken. If a machine could be devised to evaluate $\int y^2 dt$ with sufficient accuracy, its employment might best solve the diffiulty. What Bidlingmaier did in the first instance was to measure the curve at 6-minute intervals. Presumably these measurements were made at 3, 9, 15 . . . 57 minutes from the commencement of the hour. Calling the differences of the successive readings from the mean of the ten $\eta_1 \ldots \eta_{10}$,

$$(1/10)\ (\eta_1^2 + \ldots + \eta_{10}^2) = (1/10)\ \Sigma\, \eta^2$$

supplied the quantity desired.

The labour of measuring all curves at 6-minute intervals appeared prohibitive to Bidlingmaier, as it well might, and he adopted the following procedure: Employing a special scale invented by Prof. Ad. Schmidt, he measured the hourly ranges of a number of Wilhelmshaven curves for D (declination) and H. The measure-

ments presumably are effected rapidly, the quantity read off being *half* the hourly range, or what Bidlingmaier calls the "Amplitude." These "amplitudes" were apparently measured only to 1.0 mm., and the hours which had the same amplitude were combined in one group. Each amplitude from 1 to 10 mm. was represented by 25 hours in D-curves, and 25 hours in H-curves, giving 250 hours in all for either element. The curves during these hours were read at 6-minute intervals, and $(1/10)\ \Sigma\eta^2$ duly calculated for each hour. The mean values for the several groups were as follows:

		1	2	3	4	5	6	7	8	9	10^{mm}	
"Amplitude"		1	2	3	4	5	6	7	8	9	10^{mm}	
Range		2	4	6	8	10	12	14	16	18	20^{mm}	
$(1/10)\ \Sigma\eta^2$ from	D	0.30	1.33	3.50	7.2	11.8	17.1	23.2	30.0	37.8	46.5	$(^{mm})^2$
" "	H	0.34	1.26	3.46	6.3	11.1	16.3	21.8	27.7	34.8	44.1	"
" "	Mean	0.32	1.30	3.48	6.8	11.4	16.7	22.5	28.8	36.3	45.3	"

Representing amplitudes on a horizontal axis of co-ordinates, and the final mean values of $(1/10)\ \Sigma\eta^2$ on a vertical axis, Bidlingmaier connected by straight lines the 10 points thus reached, and the first point with the origin of co-ordinates. The curve thus formed had a sufficiently regular outline to suggest that accidental features were fairly eliminated, and Bidlingmaier concluded that the results thus obtained would enable him in the future to dispense with actual measurements other than those of the hourly ranges. Having found the "amplitude," he could immediately from his table write down the corresponding $(1/10)\ \Sigma\eta^2$. This procedure was fully illustrated by reference to the Wilhelmshaven declination for March 1911.

§4. Bidlingmaier's procedure seemed of sufficient promise to Prof. van Everdingen of De Bilt to merit a preliminary trial. Accordingly he invited a few observatories to join De Bilt in applying the scheme to the curves of some specified months, with a view to judging of its suitability for general adoption. This invitation was addressed to Kew Observatory amongst others, and the Director of the Meteorological Office consulted the Gassiot Committee of the Royal Society on the subject. Their opinion was against participation in the scheme. Speaking only for myself, there were several strong arguments against participation. First, the Kew curves, being artificially disturbed, were not a suitable medium for a fair trial. This was not conclusive, because Eskdalemuir curves could have been used. A more serious objection was the amount of labour involved. The curves for a

few months could no doubt have been dealt with, but there seems little use in giving a project a preliminary trial unless there is a reasonable prospect of providing the labour its ultimate adoption would entail. A final consideration was that the adoption of Bidlingmaier's table of relations between hourly "activity" and "amplitude"—which Prof. van Everdingen's scheme assumed—did not seem satisfactory without further investigation. Even if Bidlingmaier's relations were good for all time at Wilhelmshaven, it did not follow that they would be equally satisfactory at all other stations. It seemed to me that an independent test of Bidlingmaier's "activity"-"amplitude" relations on a comprehensive scale should precede any such scheme as that of Prof. van Everdingen.

As it happened, I had at my disposal at the time a large mass of material which seemed well adapted for the purpose, and the investigation seemed likely besides to lead to results of independent physical interest. A series of 36 term-hours had been selected in 1910 in anticipation of the Scott Antarctic Expedition of 1911-1912, and the invitation issued to observatories to take quick-run magnetograms during these term-hours, and to transmit the results to England for intercomparison, had met with a most generous response. Curves or curve-measurements were received from 24 observatories. The curves from three of these seemed wholly unfit for the measurement of "activity," owing to artificial disturbances, and the same was true of the vertical intensity curves at a fourth station. There was also absence of record on more than one term-hour at most stations, and several sent no vertical intensity curves. Still the material available represented about 1700 hour-runs, or more than three times as much as Bidlingmaier employed for determining his "activity"-"amplitude" relations. The use of the material for this purpose is without prejudice to its further use, and it will I hope be accepted by the contributing observatories as a partial recognition of the value of their contributions.

§5. Before discussing the results of the investigation, it will be convenient to deal with some features of Bidlingmaier's method, as their real significance did not at once dawn upon me, and may have equally escaped the attention of others. It will presumably be conceded that the phenomena presented by Nature at a given station should be independent of the peculiarities of the instrument by which they are recorded. In some branches of geophysics,

e. g., atmospheric electricity, and in the case of most of the meteorological elements, it must be confessed that the presence of instruments and observers interferes to some extent with Nature's manifestations, but the mere existence of a particular sensitiveness in a magnetograph does not affect magnetic phenomena in its neighbourhood. Suppose, however, we have working at the same station two H-magnetographs, differing only in that the sensitiveness is 1 mm. $=8\gamma$ in the one and 1 mm. $=4\gamma$ in the other, and suppose the range of H during a particular hour to be 32γ. The range shown will be 4 mm. in the one magnetogram and 8 mm. in the other. Referring to the final mean values in Bidlingmaier's table, we get

$$(1/10)\ \Sigma\eta^2 = 1.30 \text{ mm}^2. \text{ in the first case, and}$$
$$= 6.8 \text{ mm}^2. \text{ in the second case.}$$

Converting to intensity units, we get

$$8\pi\ (\text{"Activity"}) = 1.30 \times 8^2\gamma^2 = 83\gamma^2 \text{ in the first case, and}$$
$$= 6.8 \times 4^2\gamma^2 = 109\gamma^2 \text{ in the second case.}$$

Thus two numbers which ought to be identical are roughly in the ratio of 7 : 9.

It is possible, of course, that while the true "activity" must be independent of instrumental peculiarities, the results obtained by actual curve-measurements may vary with the sensitiveness. This is in fact more than a possibility, because, if the sensitiveness is sufficiently reduced, movements will become invisible which could be seen and measured on the trace of a more sensitive instrument. This is, however, by the way. The difficulty, whatever its precise cause, could be turned if an old recommendation of the International Magnetic Commission were generally adopted. The recommendation in question was in favour of a uniform sensitiveness in magnetographs, 1 mm. $=5\gamma$ being that suggested. One serious obstacle to the general acceptance of any such suggestion is that a declination-magnetograph of given design has a sensitiveness which varies inversely as the local value of H. If the ordinary Eschenhagen D-magnetograph, in which 1 mm. of ordinate represents approximately $1'$ of arc, is used at a station where $H=.172$ C. G. S., it will have the sensitiveness 1 mm. $=5\gamma$; but if used where $H=.360$ C. G. S., the sensitiveness will be 1 mm. $=10.5\gamma$. As a matter of fact, the D- and H-magnetographs employed by Bidlingmaier himself differed in sensitiveness, 1 mm. representing 6.05γ in D but 4.45γ in H, and the values he found

for $(1/10)\ \Sigma\eta^2$ from the D-curves were slightly larger than those he got from the H-curves.

The magnetographs at the stations cooperating in the 1911-12 programme showed a great range of sensitiveness. At Alibag (Bombay) 1 mm. represented 11γ in D-curves, 9.3γ in V-curves and 4.6γ in H-curves. At Cheltenham the equivalent of 1 mm. varied from 2.49γ to 1.66γ in H, and from 7.33γ to 3.46γ in V. At Seddin all the instruments were highly sensitive, the equivalent of 1 mm. varying from 2.44γ to 1.96γ. At some stations the sensitiveness of the H- and V-instruments seems to be continually altering, and if the measured "activity" depended much on the sensitiveness there would be considerable complication.

§6. On consideration it was at once obvious that the calculated "activity" must vary with the sensitiveness unless we have

$$(1/10)\ \Sigma\eta^2 = C\ R^2 \qquad (1)$$

R being the range for the hour, and C, a constant. From Bidlingmaier's table we get the following values for $(1/10)\ \Sigma\eta^2/R^2$

R	=	2	4	6	8	10	12	14	16	18	20 mm.
$(1/10)\ \Sigma\eta^2/R^2$	=	.080	.081	.097	.106	.114	.116	.115	.113	.112	.113

The relation (1) is thus very approximately satisfied for ranges from 20 to 10 mm., but the ratio becomes markedly less as the range is further reduced. Moreover, with ordinary sensitiveness, hourly ranges as large as 10 mm. are comparatively few. Thus the law appears to fail where its importance, if true, would be greatest. It is of course obvious that $(1/\tau R^2)\int_0^\tau \eta^2\, dt$, which $(1/10)\ \Sigma\eta^2/R^2$ represents, must have widely different values in individual cases. For instance, η might have the values $+R/2$ and $-R/2$ for equal times $\tau'/2$, being zero for the remaining time τ-τ^1. In this case $(1/\tau R^2)\int_0^\tau \eta^2\, dt = \tau^1/4\,\tau$, and so may have any value between $1/4$ and 0. At the same time, on the average of a large number of hours, $\Sigma\eta^2/R^2 = C$ may be expected to hold provided the shape of the curve has no tendency to alter in a definite direction as R alters.

The first question that suggests itself is as to how the results were affected by Bidlingmaier's method of grouping the observations. Apparently he determined the amplitude to the nearest 1 mm.—i. e., the range to the nearest 2 mm.—with a special piece of apparatus, and then proceeded to take *accurate* measurements at 6-minute intervals. These latter measurements would naturally

disclose any conspicuous deficiency in the amplitude accepted. We may thus presumably assume that all hours included in the group assigned a range of $2n$ mm. had ranges lying between $(2n-1)$ and $(2n+1)$ mm. Let us consider what would happen if ranges were determined to 0.1 mm., and all values from $(2n-0.9)$ mm. to $(2n+0.9)$ mm. were equally numerous. There would in reality of course be ranges exactly $(2n-1)$ and $(2n+1)$ mm., but as some of these would probably go to one group, and some to another, it will save complication to leave them out as this will not affect the general argument. We should then have 19 sub-groups, all contributing to Bidlingmaier's group of amplitude n mm. It is easily seen that

$$(2n-0.9)^2+(2n-0.8)^2+\ldots+(2n+0.9)^2=19\left\{(2n)^2+0.3\right\}$$

If a relation $(1/10)\,\Sigma\eta^2/R^2=C$ really held, we see that the value of R appropriate to the nth group would be not $2n$ but $\left\{(2n)^2+0.3\right\}^{\frac{1}{2}}$mm. The value derived from $(1/10)\ \Sigma\eta^2/R^2$ from group n would be not the true C but C_n, where $C_n=C(1+0{\cdot}3/4n^2)$, approximately.

Thus $C=C_1/(1{\cdot}075)=C_2/(1{\cdot}02)=C_3/(1{\cdot}01)$ approximately, and so on. Clearly the difference between C_n and C would be inappreciable except in the first two or three groups, and only in the first group would it be considerable. Further C would be always less than C_n, thus we do not in this way reach any explanation of the apparent fall in C_n in Bidlingmaier's lower groups. The phenomenon observed would, however, obviously arise if the number of hours in the sub-groups $(2n-0{\cdot}9)$ to $(2n+0{\cdot}9)$ mm. diminished as the range increased. As we shall see presently, this is exactly what did happen at most of the cooperating stations during the term-hours. The difference between $(2n+0{\cdot}9)^2$ and $(2n-0{\cdot}9)^2$, viz., $7{\cdot}2n$, is far from negligible compared with $4n^2$, for values of n less than 5. It is thus pretty clear that without further information as to the frequency distribution of ranges in Bidlingmaier's groups, we cannot draw any certain conclusion from his figures as to the failure or success of the hypothesis $(1/10)\ \Sigma\eta^2=C\,R^2$.

§7. The term-hour curves from the cooperating stations were all carefully measured by Mr. James Foster, a retired assistant of the Kew Observatory, ordinates being read to the nearest 0.1 mm. Measurements were made at 5-minute intervals, in preference to Bidlingmaier's 6-minute intervals, chiefly because the quick-run curves were taken with the drum rotating at 12 times the usual speed, thus the ordinary hour-breaks occurred

at 5-minute intervals. Another reason was an opinion expressed by Bidlingmaier that an increase in the hourly number of measurements was probably desirable, especially in high latitudes where disturbances are larger than at Wilhelmshaven. The first measurement was taken exactly at the hour, and not 2½ minutes after it, so that there were really 13 measurements in the hour. The first and last of these, of course, belonged equally to the adjacent hours. This was done partly because the hour-break facilitated fixing the time, and partly for another reason. I had, after some consideration, decided to derive the hourly ranges not from an independent set of measurements, but from the 5-minute readings. Now, during a quiet time, the ordinate will, in most cases, be either falling or rising throughout the whole of an hour, and the most natural times for the extreme values to present themselves are the beginning and end of the hour. It was thus obviously desirable to cover these times in the 5-minute readings. Calling the 13 measurements in the hour $y_0, y_1 \ldots\ldots y_{12}$, the mean hourly value is $\left\{\frac{1}{2}(y_0+y_{12})+y_1+\ldots+y_{11}\right\}/12$. Also the differences from this mean being $\eta_0 \ldots \eta_{12}$, the equivalent for $(1/\tau)\int_0^\tau \eta^2\,dt$ is

$$(1/12)\,\Sigma\eta^2 = \left\{\tfrac{1}{2}(\eta_0^2+\eta_{12}^2)+\eta_1^2+\ldots+\eta_{11}^2\right\}/12$$

To get an idea of how closely the sum usually represents the integral, take what we may regard as the normal quiet hour with a uniform slope in the curve. Putting $\eta=a(t-\tau/2)$, a being a constant, we get

$$(1/\tau)\int_0^\tau \eta^2\,dt = (1/3)\,(R/2)^2 = 0.0833\,R^2,$$

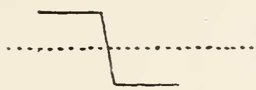
while $\left\{\frac{1}{2}(\eta_0^2+\eta_{12}^2)+\eta_1^2+\ldots+\eta_{11}^2\right\}/12\,R^2 = 146/12^3 = 0{\cdot}0845$ approx.

Before dealing with the results actually obtained, it is desirable to consider what are the possible limits of $(1/12)\,\Sigma\eta^2/R^2$. The ratio would be as large as possible if each measurement were either $+R/2$ or $-R/2$. This would occur in a uniform oscillation of amplitude $R/2$ and 5-minute period, if the maximum phase came at the beginning of the hour. In this case $(1/12)\,\Sigma\eta^2/R^2=0.25$ (Case 1). Obviously, however, it would make all the difference in such an oscillation whether the maximum phase fell exactly at the hour, or 2½ minutes after it; in the latter event each value of η would be zero. As a matter of fact, such absolutely regular oscillations rarely if ever occur in terrestrial magnetism, and "pulsations" which present the nearest approach to such an ideal

are usually of small amplitude. A result, however, nearly as large as in Case 1 is obtained in Case 2 where the first six values of η are $+R/2$ (or $-R/2$), and the last six are $-R/2$ (or $+R/2$), the central value being nil. In this case $(1/12)\ \Sigma\eta^2/R^2 = 11/48 = 0.23$ approx. The extreme form of Case 2 was not encountered, but approximations to it, represented by two nearly flat portions of curve with an intervening short portion at a steep slope, were not infrequent. In fact, nearly every instance of an individually large value of $(1/12)\ \Sigma\eta^2/R^2$ was found on investigation to approach Case 2.

Case 1.........

Mean Value.

Case 2.........

Mean Value.

Case 3.........

Mean Value.

Case 4.........

Mean Value.

Case 5.........

Mean Value.

Other cases worth notice are Nos. 3, 4, and 5. In Nos. 3 and 4 one reading differs from the others; in No. 4 it is the first (or last) reading. In No. 5 all the η's are zero, except the first, and last, which are equal and opposite. The values of $(1/12)\ \Sigma\eta^2/R^2$ in the three cases are, approximately, .076 in No. 3, .040 in No. 4, and .021 in No. 5.

An isolated "tooth" of considerable amplitude, the case illustrated by No. 3, does occasionally arise; but in the term-hours No. 3 was represented mainly in the case of very quiet curves, a single reading differing 0.1 mm. from the others. Practically every instance in which $(1/12)\ \Sigma\eta^2/R^2$ was conspicuously small showed an approach to either No. 4 or No. 5. Between Nos. 1 and 5, which seem the extreme cases, $(1/12)\ \Sigma\eta^2/R^2$ varies from .25 to .02. While a close approach to either extreme value of the ratio will naturally be rare, we must obviously look to a wide range of the ratio in practice in individual cases. No scheme such as Bidlingmaier's can be satisfactory for individual hours, a fact of which Bidlingmaier himself was obviously aware especially in the case of the smaller ranges, where he found the percentage variation largest. What immediately interested him, however, was not individual hourly values, but the mean from the 24 hours of the day, and he would probably have pointed to the fact that eccentricities in individual hours must tend to neutralise one another. While there is something in this contention, there is less than might appear at first sight. If we may judge from the data for the month which Bidlingmaier used to illustrate his methods, the mean value for the day is often mainly dependent on the contributions of 2 or 3 hours so far as his $A^x_{h,24}$ is concerned.

§8. Table 1 shows the results obtained when all hours having the same range in mm. were grouped together, irrespective of the observatory from which the data were derived, or the sensitiveness of the magnetograph.

The values of $(1/12)\ \Sigma\eta^2$ from the curves of the three elements are given separately in columns 6 to 8. Two stations, Seddin and Eskdalemuir, recorded north and west components instead of H and D. Their north-component data were treated under H, and their west component data under D. The value of R being the same for all members of the same group, some of the sources of uncertainty affecting Bidlingmaier's results are absent. On the other hand, in a good many of the groups, especially in the case of the larger V-ranges, the number of data was insufficient to eliminate accidental features. Even in the more numerously represented groups irregularities present themselves. For ranges from 0.1 to 0.7 mm. the value of $(1/12)\ \Sigma\eta^2$ appears larger for D than for H. Supposing this difference, which is not large, to be real, it may not imply any real difference between D and H, but merely

TABLE 1.—*Ranges in mm. and "Activities" in (mm.)*^{2}

Range mm.	Number of Hours				Mean Value of $(1/12)\ \Sigma\eta^2$ in mm^2.				$(1/12)\ \Sigma\eta^2/R^2$
	D	*H*	*V*	All	*D*	*H*	*V*	All	
0.1	35	4	24	63	.0019	.0015	.0015	.0017	0.17
0.2	67	12	70	149	.0053	.0050	.0052	.0052	0.13
0.3	69	23	62	154	.0096	.0093	.0093	.0094	0.104
0.4	48	30	58	136	.0156	.0136	.0148	.0148	0.092
0.5	48	33	53	134	.0248	.0219	.0245	.0240	0.096
0.6	37	32	39	108	.0342	.0332	.0328	.0334	0.093
0.7	38	39	36	113	.0470	.0459	.0476	.0468	0.096
0.8	41	37	28	106	.0643	.0644	.0624	.0638	0.100
0.9	35	23	19	77	.0746	.0816	.0783	.0776	0.096
1.0	37	51	27	115	.0951	.0921	.0979	.0944	0.094
1.1	15	18	12	45	.1156	.1410	.1200	.1269	0.105
1.2	23	28	14	65	.1370	.1257	.1384	.1324	0.092
1.3	14	24	8	46	.1545	.1607	.1709	.1606	0.095
1.4	11	21	8	40	.1757	.1979	.1743	.1870	0.095
1.5	8	16	7	31	.239	.203	.209	.214	0.095
1.6	10	11	8	29	.228	.237	.215	.228	0.089
1.7	13	15	5	33	.245	.254	.226	.246	0.085
1.8	12	28	1	41	.299	.291	199	.291	0.090
1.9	3	15	5	23	.361	.283	.291	.295	0.082
2.0	8	26	9	43	.341	.382	.356	.369	0.092
2.1	7	20	4	31	.454	.390	.403	.406	0.092
2.2	7	11	1	19	.484	.452	.562	.469	0.097
2.3	4	7	3	14	.473	.451	.521	.472	0.089
2.4	8	10	2	20	.562	.552	.722	.573	0.099

a geographical peculiarity. The Indian stations contributed the great majority of the smaller *D*-ranges, but no exceptional proportion of the smaller *H*-ranges. To a first approximation, the differences between the values of $(1/12)\ \Sigma\eta^2$ from the three elements may be neglected. It thus appeared sufficient to give for each group a single value of $(1/12)\ \Sigma\eta^2/R^2$, allowing to each element a weight proportional to the number of hours it supplied. If we omit the two smallest ranges, while the figures in the last column show fluctuations, they show no systematic departure from constancy. The mean from the 22 ranges 0.3 to 2.4 mm. is 0.094. As regards the first two ranges, the data from the different magnetic elements alike pointed to a high value of $(1/12)\ \Sigma\eta^2/R^2$. Considering, however, that readings were taken only to 0.1 mm., it is difficult to say what significance attaches to results for ranges so small as 0.1 or 0.2 mm. The real value of R^2 for members of the first group would vary from $(0.05)^2$ to $(0.15)^2$, the larger value being nine times the smaller. Thus the data grouped together would be in reality highly heterogeneous.

For ranges exceeding 2.4 mm. grouping of a different character was necessary to get at all an adequate number of entries. Table 2 gives the results obtained from the enlarged groups.

Table 2 omits ranges less than 0·3 mm., but the first three groups, and the fourth in part, embody the material already employed in Table 1. This was done to secure continuity. The range-interval in each of the first 10 groups is only 0·5 mm. For

TABLE 2.—*Ranges in mm. and "Activities" in (mm.)*^{2}.
Larger Groups.

Range From	Range To	Central Range	Number of Hours in Group	Mean Value of $(1/12)\ \Sigma\eta^2$	Value of $(1/12)\ \Sigma\eta^2/R^2$
mm.	mm.	mm.		mm.^{2}	
0.3	0.7	0.5	645	0.0242	0.097
0.8	1.2	1.0	408	0.0929	0.093
1.3	1.7	1.5	179	0.2023	0.090
1.8	2.2	2.0	157	0.357	0.089
2.3	2.7	2.5	65	0.569	0.091
2.8	3.2	3.0	55	0.846	0.094
3.3	3.7	3.5	48	1.10	0.090
3.8	4.2	4.0	25	1.42	0.089
4.3	4.7	4.5	30	1.89	0.093
4.8	5.2	5.0	21	2.25	0.090
5.5	6.5	6.0	14	3.11	0.086
6.5	7.5	7.0	8	4.39	0.090
7.5	8.5	8.0	5	6.20	0.097
8.5	9.5	9.0	5	8.25	0.102
9.5	10.5	10.0	3	9.39	0.094
Individual Cases		11.0 (*H*)	1	6.25	0.052
		11.9 (*H*)	1	13.99	0.099
		12.5 (*H*)	1	15.20	0.097
		12.7 (*D*)	1	14.00	0.087
		12.9 (*H*)	1	19.95	0.120
		14.2 (*H*)	1	25.42	0.126
		15.2 (*D*)	1	25.58	0.111
		16.3 (*H*)	1	25.71	0.097
		17.8 (*H*)	1	37.09	0.117
		18.0 (*H*)	1	40.70	0.126
		25.1 (*H*)	1	63.12	0.100

the 5 higher groups it is 1·0 mm., and even so the entries are somewhat few. Considering the number of hours available for the higher groups, the fluctuations in the figures in the last column for the 15 groups are remarkably small. In computing the values of $(1/12)\ \Sigma\eta^2/R^2$ the arithmetic mean value of $(1/12)\ \Sigma\eta^2$ was divided by the value of R^2 corresponding to the centre of the range-

interval. It would of course have been in some ways better to divide the value of $(1/12)\ \Sigma\eta^2$ for each individual hour by its true R^2, and to take the arithmetic mean of the products thus formed, but the additional labour this would have involved seemed hardly justified.

Only 11 ranges, none of them V-ranges, exceeded 10 mm. The results from these are given individually in Table 2, the element, D or H, concerned being shown in brackets. The values of $(1/12)\ \Sigma\eta^2/R^2$ thence obtained are in 9 cases out of 11 in excess of the mean, 0·092, derived from the fifteen groups. This suggests a tendency in $(1/12)\ \Sigma\eta^2/R^2$ to increase when R becomes very large. Of the 5 cases, however, in which H-curves gave a value exceeding 0.1, 4 were supplied by Cheltenham, De Bilt or Seddin, stations where the sensitiveness was exceptionally high, 1 mm. representing from 1·6 to 3.3γ. Thus the ranges to which the apparent rise in $(1/12)\ \Sigma\eta^2/R^2$ is mainly due were not in reality exceptionally large.

§9. An entirely independent investigation was carried out with the ranges and activities expressed in terms of intensity. The results appear in Table 3. The number of hours having ranges identical to 0.1γ was somewhat limited, thus different ranges had to be grouped together. In the first 10 groups the range interval was 0·5γ; in the next 10 it was 1·0γ. In obtaining the values of $(1/12)\ \Sigma\eta^2/R^2$ for these twenty groups, the mean value of $(1/12)\ \Sigma\eta^2$ was found for the group and the divisor R^2 then applied to it. The value assigned to R was not, however, as in Table 2, that answering to the centre of the range-interval, but the actual arithmetic mean of all the individual ranges included in the group. The three elements were treated independently.

In the case of the first 20 groups in Table 3, the value assigned in the last column to $(1/12)\ \Sigma\eta^2/R^2$ was obtained by weighting the results for D, H, and V proportionally to the number of hours included. Ranges exceeding 15γ were arranged in 6 groups whose limits are shown in the table; the data for D, H and V were all combined. In this case $(1/12)\ \Sigma\eta^2/R^2$ was calculated separately for each individual observation, the exact value of R^2 being inserted in the denominator, and the arithmetic mean of the products is what appears in the last column.

Corresponding to the phenomenon exhibited in Table 1, the first group in all three elements, and the next 3 groups in the

TABLE 3.—*Ranges in γ and "Activities" in γ^2.*

Range		No. of Hours			Mean Ranges			Mean Values of $(1/12)\ \Sigma\eta^2$			$\{(1/12)\ \Sigma\eta^2\}/R^2$			
From	To	D	H	V	D	H	V	D	H	V	D	H	V	All
γ	γ				γ	γ	γ	γ^2	γ^2	γ^2				
0.1	0.5	1	3	19	0.50	0.50	0.40	0.050	0.044	0.025	.200	.178	.160	.164
0.6	1.0	23	9	56	0.85	0.86	0.86	0.136	0.069	0.098	.188	.094	.132	.143
1.1	1.5	37	27	65	1.26	1.28	1.31	0.242	0.159	0.188	.152	.098	.109	.119
1.6	2.0	43	45	69	1.77	1.84	1.80	0.406	0.324	0.353	.130	.096	.109	.111
2.1	2.5	57	35	51	2.29	2.29	2.27	0.590	0.489	0.481	.113	.093	.093	.101
2.6	3.0	45	48	53	2.86	2.77	2.77	0.727	0.828	0.766	.089	.108	.100	.099
3.1	3.5	60	42	34	3.36	3.31	3.27	1.109	0.944	0.970	.098	.086	.091	.092
3.6	4.0	26	45	40	3.81	3.75	3.78	1.39	1.27	1.26	.096	.090	.088	.091
4.1	4.5	41	44	24	4.29	4.30	4.31	1.73	1.74	1.68	.094	.094	.090	.093
4.6	5.0	26	39	23	4.70	4.76	4.74	2.32	2.25	2.25	.105	.099	.100	.101
5.1	6.0	57	76	34	5.53	5.55	5.49	2.97	2.95	2.91	.097	.096	.097	.097
6.1	7.0	34	54	26	6.63	6.49	6.55	3.93	4.00	3.98	.089	.095	.093	.093
7.1	8.0	35	35	15	7.58	7.52	7.59	5.49	5.07	5.18	.096	.090	.090	.092
8.1	9.0	34	31	15	8.66	8.47	8.65	7.51	5.87	7.36	.100	.082	.098	.093
9.1	10.0	32	26	6	9.61	9.55	9.73	8.62	7.76	9.28	.093	.085	.098	.090
10.1	11.0	16	21	3	10.61	10.49	10.30	10.54	10.83	11.59	.094	.098	.109	.097
11.1	12.0	10	18	1	11.55	11.52	11.30	11.89	12.08	17.98	.089	.091	.141	.092
12.1	13.0	14	16	3	12.44	12.43	12.50	15.45	13.06	16.56	.100	.085	.106	.093
13.1	14.0	11	15	1	13.50	13.61	14.00	15.11	15.41	17.69	.083	.083	.090	.083
14.1	15.0	10	6	3	14.59	14.73	14.47	20.19	20.89	18.89	.095	.096	.090	.095
15.1	17.5	41			16.4									.092
17.6	20.0	21			18.7									.096
20.1	25.0	36			22.1									.093
25.1	30.0	20			27.0									.091
30.1	40.0	15			33.4									.105
>40.0		11			50.3									.109

case of D and V, show an apparent increase in $(1/12)\ \Sigma\eta^2/R^2$ as R is reduced. Omitting the first 4 groups, the mean values of $(1/12)\ \Sigma\eta^2/R^2$ from the next 16 groups are ·096 from D, ·092 from H, ·098 from V, and .094 from the three elements combined. The final mean for V falls to ·096 if we omit the 17th and 19th groups which contained only one V-range each. There is no suggestion of an increase in $(1/12)\ \Sigma\eta^2/R^2$ as R rises from 2γ to 30γ. The last two groups in Table 3 do give enhanced values, but the number of observations included is somewhat limited. In the last group there were only 11 hours, while the individual values obtained for the ratio varied from ·067 to ·151.

§10. An attempt was made to ascertain whether $(1/12)\ \Sigma\eta^2/R^2$ varied with the hour of the day, the season of the year, or the

geographical position of the station. Two groups of stations were principally considered, Group I including 6 western European stations, Eskdalemuir, Stonyhurst, De Bilt, Uccle, Seddin and Val Joyeux, and Group II including the southern Asiatic stations, Dehra Dun, Barrackpore, Toungoo, Alibag and Kodaikanal. The H-ranges in γ and corresponding "Activity" results in γ^2 were considered separately for the two groups of stations; and in the first instance a separate investigation was effected for the hours 8^h to 10^h (G. M. T.) in May, June and July, for the hours 17^h to 19^h in the same three months, and finally for the hours 18^h to 20^h in the months of November, December and January.

TABLE 4.—*Comparison of European and Asiatic Stations.*

Range		Number of Hours		Mean Range		Mean Value of $(1/12)\ \Sigma\eta^2$		Value of $(1/12)\ \Sigma\eta^2/R^2$	
From	To	Group I	Group II	Group I	Group II	Group I	Group II	Group I	Group II
γ	γ			γ	γ	γ^2	γ^2		
1.0	1.9	16	21	1.44	1.52	0.222	0.245	.107	.106
2.0	2.9	25	15	2.44	2.45	0.644	0.566	.108	.094
3.0	3.9	18	21	3.41	3.57	1.03	1.24	.089	.098
4.0	4.9	13	31	4.32	4.54	1.64	2.15	.088	.104
5.0	5.9	23	17	5.42	5.54	2.63	3.15	.090	.103
6.0	6.9	23	14	6.42	6.35	3.82	4.12	.093	.102
7.0	7.9	10	7	7.52	7.34	4.72	6.11	.083	.113
8.0	8.9	10	4	8.36	8.28	5.51	4.86	.079	.071
9.0	9.9	8	9	9.57	9.47	7.10	8.11	.078	.090
10.0	10.9	8	5	10.40	10.56	10.21	12.55	.094	.112
11.0	11.9	5	4	11.48	11.30	11.80	12.86	.090	.101
12.0	12.9	9	4	12.44	12.23	13.01	14.68	.084	.098
13.0	13.9	6	1	13.62	13.30	15.37	17.64	.082	.100
Arithmetic mean from all the groups								.090	.099
" " " all but first group								.088	.099

No certain difference was found as between different hours or different seasons at the same group of stations, but the data in the several categories were too few to lead to a decisive result. When, however, all the data belonging to the same group of stations were combined, a fairly decisive difference appeared between the European and Asiatic groups, as will be seen on consulting Table 4, where the ranges from 1.0 to 13.9γ are arranged in 13 sub-groups. The mean ranges given in the fifth and sixth columns were employed in calculating the values of $(1/12)\ \Sigma\eta^2/R^2$ in the last two columns. As the Asiatic value was the larger in 10 cases out of 13, and its average excess was about ten per cent, the reality

of the difference can hardly be questioned. It is conceivable, however, that it represents instrumental rather than geographical influence. Watson magnetographs were in use at 4 of the Indian stations, and the data supplied from these stations consisted of eye readings taken by members of the local staffs. The European data, on the contrary, were all from photographic curves measured by one man.

A similar investigation was carried out, employing the H-range data in mm. and the corresponding "activity" data in mm^2., for the same two groups of European and Asiatic stations, and for a third group composed of the 7 American (North and South) stations, Sitka, Agincourt, Cheltenham, Tucson, Honolulu, Vieques and Pilar. Ranges from 1·8 to 5·2 mm. were arranged in 7 subgroups, for each of the three groups of stations. The largest value for $(1/12)\ \Sigma\eta^2/R^2$ was supplied 4 times by the Asiatic, twice by the American and once by the European stations; whilst the smallest value was supplied 5 times by the European group and only twice by the American. The results thus point in the same direction as those in Table 4 so far as the European and Asiatic stations are concerned, and they make the American stations intermediate between the other two groups. This investigation, it should be clearly understood, means no more than that for certain hours on certain selected days a difference in the value of $(1/12)\ \Sigma\eta^2/R^2$ manifested itself between certain groups of stations. If data from all hours of the day had been used, or if the comparison had been between stations in the same latitudes of Europe, Asia and America, the results might have been different.

§11. The mean values obtained in Table 4 for $(1/12)\ \Sigma\eta^2/R^2$ from the two groups of stations differ in opposite directions and about equally from the mean derived from all the cooperating stations. Thus, so far as we have gone, there is no evidence that large errors would arise at any individual station by employing the general mean value of C. When, however, we pass to the results derived from the term-hour records at the Scott Antarctic station, which are given in Table 5, it is rather different. In this table the data from the three magnetographs—recording, respectively, the east, south and vertical components—are combined.

Two sets of data, bracketed and unbracketed, are given for the range and $(1/12)\ \Sigma\eta^2/R^2$. The unbracketed figures are exactly

parallel to those in our previous tables. They depend on hourly ranges derived from the 5-minute measurements. These are the ranges by reference to which the hours were grouped, and it is to them that the figures in the first two columns refer. The data in brackets refer to the absolute ranges obtained by measuring the largest and least ordinates of the hour irrespective of when they occur. Each bracketed figure refers to identically the same hours as the unbracketed figure to which it is juxtaposed. The value of $(1/12)\ \Sigma\eta^2/R^2$ for each group was found by dividing the mean value of $(1/12)\ \Sigma\eta^2$ for the group by the square of the corresponding mean range as given in the fourth column. The 11 hours in which the range as derived from the 5-minute intervals exceeded 9 mm. —which meant at least 58γ—were treated individually. Of these 11 hours' curves 8 were supplied by the E, 2 by the S and 1 by the V magnetograph.

Considering first the unbracketed data, while the values obtained for $(1/12)\ \Sigma\eta^2/R^2$ fluctuate a good deal, as was inevitable

TABLE 5.—*Antarctic Ranges and "Activities."*

Range From	Range To	No. of Hours	Mean Range		Mean Value of $(1/12)\ \Sigma\eta^2$	$(1/12)\ \Sigma\eta^2/R^2$	
mm.	mm.		mm.	mm.	mm.[2]		
0.4	0.5	5	0.44	(0.48)	0.0126	.065	(.055)
0.6	1.0	13	0.88	(1.00)	0.0632	.082	(.063)
1.1	1.5	9	1.34	(1.63)	0.125	.070	(.047)
1.6	2.0	14	1.79	(2.06)	0.289	.090	(.068)
2.1	3.0	13	2.50	(2.94)	0.471	.075	(.055)
3.1	4.0	6	3.88	(4.45)	1.392	.092	(.070)
4.1	5.0	6	4.37	(5.37)	1.364	.072	(.047)
5.1	6.0	7	5.57	(6.20)	2.451	.079	(.064)
6.1	7.0	8	6.52	(7.15)	2.898	.068	(.057)
7.1	8.0	2	7.20	(7.85)	4.224	.082	(.069)
8.1	9.0	5	8.48	(10.08)	5.010	.070	(.049)
Individual Cases			9.5	(9.6)	7.14	.079	(.077)
			10.2	(11.7)	7.85	.076	(.057)
			10.6	(12.9)	10.92	.098	(.066)
			12.2	(12.7)	7.93	.053	(.049)
			12.6	(15.1)	17.88	.113	(.078)
			12.8	(14.7)	14.13	.086	(.065)
			14.6	(15.9)	18.97	.089	(.075)
			19.5	(29.5)	38.98	.103	(.045)
			23.9	(24.0)	54.57	.096	(.095)
			31.3	(32.6)	93.21	.095	(.088)
			40.7	(41.7)	190.56	.115	(.110)

in view of the limited number of observations in the groups, there can be no question that they fall notably short of the corresponding results in Tables 2 and 3. The mean value of the ratio from the 11 groups is only 0·077. Only one group gives a value as large as the mean in Table 2. Of the 11 larger ranges treated individually 9 give a value for the ratio exceeding ·077, and the mean of the 11 values in ·091 (see Table 2).

Considering next the bracketed figures in Table 5, we see a general tendency, not confined to the larger ranges, for the range derived from the measurements at 5-minute intervals to be sensibly in defect of the true range. The most outstanding case is that in which the 5-minute measurements gave a range of only 19·5 mm., while the true range was 29·5 mm. The true minimum in this instance occurred two minutes after the preceding 5-minute measurement, and during these two minutes the element east component, (E), fell 59γ, rising 68γ in the course of the next three minutes. The fall, when at its quickest, was at the rate of 43γ per minute. In this instance the value obtained for $(1/12)\ \Sigma\eta^2/R^2$ when the true range is used is only 44 per cent of that obtained by employing the range derived from the 5-minute measurements. Even in the case of the groups, the mean of the 11 values of $(1/12)\ \Sigma\eta^2/R^2$ falls from .077 to ·059 when the ranges derived from the 5-minute measurements are replaced by the true ranges.

The Antarctic curves are conspicuously unrestful as compared with those at ordinary stations. Even in the quietest times, oscillations and isolated tooth-like movements are not infrequent. Thus we should not expect at the ordinary station the range derived from measurements at 5-minute intervals to be as conspicuously an under-estimate as in the Antarctic, where the average deficiency was about 15 per cent. But a deficiency of even 5 per cent means a deficiency of 10 per cent in R^2; thus the way in which the hourly range is to be reached wants careful consideration before it is employed in any international scheme.

In the Antarctic curves, especially at midsummer, the times at which the hourly maximum and minimum presented themselves could usually be seen at a glance. But in the case of the cooperating stations, where many of the traces were nearly level lines, finding the maximum and minimum ordinate throughout a length of curve of from 175 to 240 mm.—the length of a quick-run hour trace—would have been an extremely laborious business, entailing a number of trial measurements. This was one of my principal

reasons for deriving the range in their case from the 5-minute measurements. Another reason was that the failure of the maximum or minimum to fall at a 5-minute measurement could not influence the value found for $\Sigma\eta^2$. A recognisable relation between $\Sigma\eta^2$ and R thus seemed more likely to arise when R was derived from the 5-minute measurements than when it represented the true absolute range.

§12. Table 6 contrasts the distribution of ranges at two representative stations and illustrates the variability of the "activities" for one and the same range. At Alibag, a station representing tropical conditions and small disturbance, the equivalent of 1 mm. of ordinate was 4.6γ in H, 9·3γ in V and 11.0γ in D. At Seddin, a much more disturbed station in temperate latitudes, the equivalent of 1 mm. varied from 1·96γ to 2·16γ in W, from 2·00γ to 2·15γ in V, and from 2·42γ to 2·44γ in N. Alibag sent records for each element for every one of the 36 term-hours. In D no range exceeded 1·4 mm.; only 4 attained to 1·0 mm., and 23 were less than 0·5 mm. At Seddin, on the other hand, no W-range fell short of 0·8 mm., only 2 fell short of 1·0 mm., and 58 per cent exceeded 2·0 mm. The ranges referred to in this connection, it will be understood, were derived from the 5-minute measurements. In Bidlingmaier's table, it will be remembered, 2.0 mm. was the range assigned for the *first* group, which presumably included ranges varying from 1·0 mm. (or 1·1) to 3·0 mm. (or 2·9). No provision was thus made for ranges less than 1·0 mm., unless it was intended to derive the corresponding "activities" from the curve, which there took the form of a straight line connecting the origin of coordinates with the point representing the range 2·0 mm. The unsuitability of this straight line for the purpose will be readily recognized if we consider, for example, the range 0·5 mm. The corresponding "activity" derived from the curve would be $(1/4)\times 0{\cdot}32$, or 0·08, whereas the mean value obtained for this range in Table 1 is only 0·024. In fact, for the range 0·5 mm. the greatest possible value of the "activity" is only $(1/4)\ (0{\cdot}5)^2$, or 0·0625. From the sensitivity figures given above it is, however, obvious that if a range of 1·0 mm. in W at Potsdam requires consideration, so also does a D-range of 0·2 mm. at Alibag.

§13. Vertical-intensity "activities" were omitted by Bidlingmaier, and Prof. van Everdingen's proposal was limited to the horizontal components. A certain number of observatories, in-

Table 6.—*Values found in Individual Hours for* (1 / 12) $\Sigma \eta^2$. (*Unit* 0.001 × 1 *mm.*^{2})

Range	ALIBAG			SEDDIN		
mm.	*D*	*H*	*V*	*W*	*N*	*V*
0.1	3	...	2, 2	...	...	...
0.2	3, 3, 4, 4, 4, 5, 5, 6, 7	...	2, 5, 9, 9	...	...	...
0.3	5, 6, 7, 7, 8, 8, 8, 11, 13	10, 11	5, 8, 9, 10, 11, 12, 12, 16	...	...	7
0.4	13, 14, 14	12, 12, 13, 15, 20	9, 9, 14, 15, 15, 16, 24	...	...	12
0.5	29, 36	11, 13, 17	14, 15, 16, 26, 26, 34	...	23	32
0.6	27	44	20	...	16	20, 44, 53
0.7	23, 40, 54	52	38, 53, 57	...	...	47, 51
0.8	57	72, 73	56, 64	105	70, 74	46, 80
0.9	55, 70	90	65	85	...	48
1.0	123, 132	43, 59, 73, 108, 124, 137	...	50, 106, 113	71	55, 78, 108
1.1	175	...	...	114	138	105
1.2	...	109, 117, 122	...	...	...	139
1.3	...	163	...	62, 163	...	...
1.4	122	108, 122	...	219	...	189
1.5	...	...	205	...	209	120
1.6	...	...	...	310	233	144, 269, 287
1.7	...	...	...	348	...	201
1.8	...	208	...	192, 289, 390	141, 271, 320	199
1.9	...	...	...	...	...	323
2.0	...	352, 409	...	432	...	...
Number > 2.0	0	6	1	21	23	10

cluding I think Wilhelmshaven, are either unprovided with vertical-intensity magnetographs or else have their vertical-intensity record spoilt by artificial disturbances. It must not be supposed, however, that the vertical-intensity contribution to the total "activity" is negligible. In the case of the internal hour activity, Bidlingmaier's $A^x_{h,24}$, taking an average from all the complete term-hours at all the cooperating stations, the vertical intensity contribution was about 10 per cent of the whole; for the Antarctic station it was 8 per cent. As it so happened, vertical intensity was relatively quieter than usual at the cooperating stations on July 17, 1911, the term-day on which disturbance was generally greatest. If we omit that day for the cooperating stations the percentage contribution from vertical intensity rises to 12. Similarly in the case of the Antarctic if we omit December 18, 1911, the most disturbed term-day there, the percentage contribution from vertical intensity rises to 17. Thus in both cases the results derived from all the term-hours combined are probably an underestimate of the relative importance of the vertical-intensity contribution on the average day.

In March 1911 at Wilhelmshaven, Bidlingmaier found for the mean values of $A^x_{h,24}$ and $A^h_{d,24}$ the respective values of 5.84ϵ and $17{\cdot}12\epsilon$, so that the contribution from the internal hour "activity" $A^x_{h,24}$ to the whole activity was only about 25 per cent. This particular month may have been far from representative, but the natural inference is that the contribution from the diurnal inequality is normally the larger in temperate latitudes. Thus in judging of the relative importance of V it is probably to the diurnal inequality that we have principally to look. To get at least an idea of how things stand there, I have considered the mean diurnal inequalities at Kew for all ordinary days of the 11-year period 1890 to 1900, and the mean diurnal inequalities in the Antarctic for all complete days of the years 1911 and 1912. At Kew the resulting value of $A^h_{d,24}$ was $10{\cdot}8\epsilon$, of which vertical intensity contributed 13 percent; the corresponding figures for the Antarctic were $61{\cdot}3\epsilon$ and 16 percent. In the mean diurnal inequalities for the whole year a great deal of cancelling goes on between the contributions from different days, so that the arithmetic mean value of $A^h_{d,24}$ from all days treated individually will at all stations be markedly in excess of the corresponding result derived from the diurnal inequalities for the year. But the cancelling out

applies to the vertical intensity as well as to the horizontal components. Thus I think we shall not be far wrong if we put the average contribution of the vertical intensity at about one-eighth of the whole. On some highly disturbed days as large movements appear in the vertical-intensity traces as in those of the horizontal components, and on such occasions the neglect of the vertical-intensity contribution would lead to a large under-estimate of the "activity." The neglect would undoubtedly in many months materially alter the order in which the days rank according to "activity."

§14. On the average term-hour the internal "activity" in the Antarctic was fully double the sum of the corresponding "activities" at all the 21 cooperating stations, while the sum of the Antarctic "activities" for the two term-hours of December 18, 1911, exceeded the "activities" from all the term-hours of all the cooperating stations. There is no reason to suppose the Scott Antarctic station disturbed above other stations in high magnetic latitudes north and south. Thus in the absence of representative Arctic and Antarctic stations, we cannot well in the meantime form anything like a trustworthy estimate of the mean "activity" on any day for the Earth as a whole. It is also pretty obvious that if we had magnetic observatories uniformly distributed over the Earth's surface, and took the arithmetic mean of all the "activities" observed, the contributions from high latitudes would almost entirely swamp those from temperate and tropical latitudes. In framing any international scheme it would be desirable to have a clear idea of exactly what it is we want to know. If it is not the average amount of "activity" over the Earth's surface as a whole, but the greater or less area over which disturbance prevails, we shall probably have to arrive at an average or normal "activity" for each station, and express the "activity" estimated for any given day in terms of this normal.

§15. The relation we have found between Bidlingmaier's $A^x_{h,24}$ and the square of the hourly range suggested that a similar relationship might hold between the mean "activity" for the day, Bidlingmaier's $A^x_{d,24}$ and the square of the daily range. Bidlingmaier gave for each day of March 1911 the values of $A^x_{h,24}$ and $A^x_{d,24}$ obtained from D and H, separately, at Wilhelmshaven, as well as the mean hourly values of D. This enabled a D-range of a kind, R_1, to be got out for each day, the value so obtained

being of course less than the absolute range derived from the two extreme values of the day. The publications of the Meteorological Office for 1911 gave the absolute daily ranges of D and H at Kew, R_2 and R_3, say, respectively. A comparison was accordingly instituted between Bidlingmaier's $A^x_{d.24}$ as given by D alone, and the corresponding values of R_1^2 and R_2^2, and again between Bidlingmaier's $A^x_{d.24}$ as given by D and H combined, and the corresponding values of $R_2^2+R_3^2$. The several quantities were expressed as percentages of their respective mean values for March, these mean values being in the case of $A^x_{d.24}$ for D alone, 12·8ϵ, for D and H combined 23.0ϵ, for R_1^2 27·9 $(1')^2$, for R_2^2 4942γ^2, and for $R_2^2+R_3^2$ 10219γ^2. The results appear in Table 7, where the "activity" results from D alone and from D and H combined are described respectively as $A(D)$ and $A(D \,\&\, H)$.

TABLE 7.—*Comparison of "Activities" and (Ranges)², expressed as Percentages.*

Date	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	
A (D)	123	23	134	85	150	58	41	37	34	32	33	39	57	69	59	
R_1^2	151	28	166	101	176	66	32	30	32	42	44	47	47	66	52	
R_2^2	114	31	157	63	111	94	31	34	34	39	29	34	61	73	48	
A (D & H)	107	22	114	67	151	70	40	67	42	30	29	54	57	58	63	
$R_2^2+R_3^2$	109	25	116	53	176	132	49	86	37	29	22	31	47	64	94	
Date	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
A (D)	47	38	47	41	429	248	111	198	135	129	219	145	119	88	61	71
R_1^2	49	42	63	49	474	186	86	120	120	86	265	138	152	82	54	54
R_2^2	59	41	29	29	558	263	120	114	160	108	211	164	129	88	23	51
A (D & H)	52	43	36	34	536	237	98	203	127	161	159	151	103	85	54	50
$R_2^2+R_3^2$	70	36	24	24	432	259	154	143	143	139	152	193	99	82	36	44

In considering the table several things should be remembered. Firstly, the "activity" results depend on Bidlingmaier's table of hourly-range "activity" data, and are thus probably seldom very exact estimates, and in some cases rather inexact estimates. Thus when considerable differences exist between the percentages for "activity" and R^2, the cause may be partly imperfection in the

former. Secondly, vertical intensity is neglected; on the average this represents some 10 per cent of the true "activity," and on individual days probably 20 or even 30 per cent. Lastly, some divergence between the data for Wilhelmshaven and Kew is inevitable, though the stations are near enough together to ensure that no day will be highly disturbed or outstandingly quiet at the one without presenting similar characteristics at the other.

Everything considered, the parallelism between the "activity" data and the $(\text{range})^2$ data is remarkably close. A formula of the type

$$A^x_{d,24} = C\,(\text{Daily Range})^2$$

would in this month at least have accorded well with the facts. The mean square of the differences between the "activity" data and the $(\text{range})^2$ data is 27 for the Wilhelmshaven D-ranges, 32 for the Kew D-ranges and 30 for the Kew D- and H-ranges combined. If we omit March 20th, much the most disturbed day of the month, these figures reduce to 26, 23 and 24, respectively. On March 20 one single hour contributed nearly one-third of the whole D "activity" for the day; thus, accident may well have played a larger part than usual in Bidlingmaier's estimate. Also on that day Bidlingmaier's estimated "activity" was considerably larger for H than for D—an exceptional phenomenon—while at Kew the D-range exceeded that in H; thus, the difference between Wilhelmshaven and Kew phenomena was very probably greater than usual. Considering the inevitable differences between Wilhelmshaven and Kew, the results suggest, though it is only a probability, that the square of the absolute daily range is a better measure of the "activity" than the square of the range which represents the difference between the largest and the least of the hourly means. The evaluation of the former range involves much less labour than that of the latter.

Summary.

On the theoretical side there is a serious objection to the universal application of Bidlingmaier's "activity"-range table. From practical as well as theoretical considerations it would be better to proceed on the hypothesis that the internal "activity" for an hour in which the range is R amounts to CR^2, where C is a constant. While the best value for C is not the same at all stations, a mean value could be assigned which would not be much in error,

except probably in high latitudes. But whether Bidlingmaier's table or the CR^2 relation were used, the necessary labour would alike be too heavy a burden at most observatories; also the few observatories that could supply the labour would probably be unable to complete the work until a year or two had elapsed. On the majority of individual hours, and on a considerable number of individual days, the accuracy obtained, whether by the use of Bidlingmaier's table or by the use of the CR^2 hypothesis, would leave a good deal to be desired.

The deduction of the mean daily "activity" at one step by assuming it proportional to the square of the absolute daily range is an alternative worth considering. For individual days, at individual stations, the results would doubtless be inferior in accuracy to those obtained by calculating hourly "activities," but in the case of an international scheme participated in by 30 or 40 stations this disadvantage would largely if not entirely disappear. The labour involved would be less than a tenth, in fact more like a hundredth, of that involved by Bidlingmaier's scheme, and would be well within the capacity of the great majority of observatories. In addition to the measurement of the daily maximum and minimum for each magnetic element—or in a restricted scheme for the horizontal components only—all that is required is a knowledge of the scale values. There would be no occasion to await the final determination of base values, and the calculation of the diurnal inequalities at the year's end. The results could thus be prepared and transmitted to De Bilt with no more delay than attaches at present to the "character" figures.

ACTIVITY OF THE EARTH'S MAGNETISM.

By D. L. Hazard.

At the request of the International Commission for Terrestrial Magnetism, the "activity" of the Earth's magnetism has been computed for each day of the year 1915 from the records of the Cheltenham Magnetic Observatory, using the method proposed by the late Dr. Bidlingmaier and explained by him in the publication of the results of the Wilhelmshaven observations for 1911.

This method takes the variability of the Earth's magnetism as a measure of its activity, that is, its departure, from moment to moment, from its undisturbed state. As we have not as yet data for determining this undisturbed state, the activity for a day is derived from the departures from the daily mean. This is divided into two parts, namely: the departure of the hourly means from the daily mean and the departure of the individual values in each hour from the mean value for that hour.

The regular observatory-tabulations contain the data for computing the first part. To simplify the evaluation of the second part (the so-called hour-integral) Bidlingmaier established a relation between the hourly range and the hour-integral by computing the hour-integral for a sufficient number of hours from ordinates measured at 6-minute intervals, and tabulating the ranges for the same hours. When the results were plotted with amplitude (half-range) as abscissa and hour-integral as ordinate, it was found that the line joining the plotted points formed a smooth curve of parabolic form.

With the request for cooperation in a study of the activity for the year 1915, it was suggested by the International Commission that other observatories might safely accept the relation between hourly range and hour-integral as determined for Wilhelmshaven, on the assumption that for ordinary magnetic latitudes the relation would be nearly constant. It was thought best, however, in the case of Cheltenham to make at least an approximate determination of the relation. Only D (declination) and H (horizontal intensity) were used for this purpose, as the variations of Z (vertical inten-

sity) were not of sufficient magnitude. A comparison of the results for Wilhelmshaven and Cheltenham is presented in the following table. The Wilhelmshaven results are derived from 25 hours of D and 25 hours of H for each amplitude. The number of Cheltenham hourly values used is given in the table.

Relation between Amplitude and Hour-Integral.

Amplitude in mm.	Hour-Integral A_h^x in mm.²		No. of Values	$A_h^x \div (2\ \text{amp.})^2$		Computed Values	
	W.	*Ch.*	*Ch.*	*W.*	*Ch.*	*W.*	*Ch.*
1	0.32	0.48	35	0.080	0.120	0.4	0.4
2	1.30	1.58	52	0.081	0.099	1.8	1.6
3	3.48	3.78	38	0.097	0.105	4.0	3.6
4	6.8	6.8	43	0.106	0.106	7.2	6.4
5	11.4	10.5	35	0.114	0.105	11.2	10.0
6	16.7	14.2	25	0.115	0.099	16.2	14.4
7	22.5	19.7	18	0.115	0.101	22.0	19.6
8	28.8	24.8	15	0.112	0.097	28.8	25.6
9	36.3	35.0	7	0.112	0.108	36.4	32.4
10	45.3	34.7	3	0.113	0.087	45.0	40.0
11	....	51.8	6	....	0.107	54.4	48.4
12	....	56.3	3	....	0.098	64.8	57.6

It will be seen that the Cheltenham hour-integrals are greater than Wilhelmshaven for amplitudes up to 3 mm. and smaller for amplitudes greater than that, but the differences are of the same order as the probable error of the hour-integral for a single hour, as determined by Bidlingmaier.

The parabolic form of the curve representing the relation between amplitude and hour-integral suggested the probability that a linear relation would be found to exist between the square of the amplitude (or the range) and the hour-integral. How nearly this is the case is shown by the quantities in the 5th and 6th columns of the table, which were obtained by dividing the hour-integral by the square of the corresponding range, (double amplitude), and also by the quantities in columns 7 and 8, which were computed from the formulas:

For Wilhelmshaven: $A_h^x = 0.1125\ (\text{range})^2$
For Cheltenham: $A_h^x = 0.100\ (\text{range})^2$

The agreement between the observed and computed values is very good, except for the large amplitudes at Cheltenham, and in those cases the observed values were derived from only a small

number of hours. It was concluded, therefore, that the use of the above formula to derive the hour-integral from the hourly range would give results of sufficient accuracy for all practical purposes. For Cheltenham it involved the simple process of dividing the square of the hourly range by ten.

An examination of the activity results for Cheltenham for 1915 indicates that the method of computing could probably be simplified still further without materially affecting the practical value of the results. The portion depending on the hour-integral is much smaller than that derived from the differences between the hourly values and the daily mean, except for days of great disturbance. This is especially true of Z and it is believed that in the case of that component the computation of hour-integrals might be confined to the disturbed days. For D and H also there are whole days and parts of many other days for which the hour-integrals might be estimated from an inspection of the magnetogram with sufficient accuracy. When the H scale-value is about 2.5γ, as at Cheltenham, the activity represented by an hourly range of 3mm. would be only 0.2×10^{-10} erg. cm.$^{-3}$ and it is questionable whether anything is to be gained by trying to differentiate between activities no larger than that.

United States Coast and Geodetic Survey,
Division of Terrestrial Magnetism, Washington, D. C.

THE INFLUENCE OF SOLAR ACTIVITY ON THE LUNAR-DIURNAL MAGNETIC VARIATION.

By S. Chapman.

In various recent papers[1] I have discussed the lunar-diurnal magnetic variation, advocating the theory that it is due to the combined influence of a lunar atmospheric tide and of a solar ionizing effect in the upper regions of the air. This theory, as I pointed out in a former note[2] in this Journal, almost inevitably requires a close parallelism between the solar- and lunar-diurnal variations, consequent upon changes in the solar activity. Many investigators[3] have examined the lunar variations to test this point, but without arriving at any general agreement upon it. Sabine, treating observations from St. Helena, Toronto, the Cape and Hobarton, Chambers and Figee dealing, respectively, with data from Bombay and Batavia, all concluded that the lunar-diurnal magnetic variation showed no regular dependence upon solar activity. On the other hand Broun, from the Trevandrum declination observations, and van der Stok, from a series of Batavia observations (shorter than that dealt with by Figee, however), concluded that the lunar-diurnal variation was greater at Sunspot maximum than at Sunspot minimum. The discrepancy was attributed by van der Stok[4] to the different methods of computation used by the various investigators of the lunar variation. This suggestion cannot really be sustained, in my opinion; the reason seems to be rather that the lunar variation is so small that accidental errors are apt to mask small changes in its amount, so that the investigation of the solar effect requires a very careful discussion of a considerable quantity of observational material. A résumé of the principal data hitherto available was given in

[1] *Phil. Trans.*, A, 213, p. 279 (1913); A, 214, p. 295 (1914); A, 215, p. 161 (1915); also a further paper dealing with both the solar- and lunar-diurnal magnetic variations, which was read before the Royal Society on March 22, 1917.

[2] *Terr. Mag.*, v. XIX, 1914, p. 39.

[3] For references see the first of my papers, cited above.

[4] Batavia Observations, IX, 1886, Appendix, p. [13].

the note referred to above, and seems to support this conclusion. The Trevandrum data show a fairly close parallelism with the Sunspot curve for the corresponding period (1854-1864), the range from Sunspot maximum to minimum being 20 or 30 per cent. A series of Greenwich data (1848-1863), and other series from Bombay (1871-1888) and Batavia (1884-1899) gave less consistent results, and it was not possible to formulate any definite conclusion regarding the influence of solar activity from the data there collected.

One point which was not emphasized in that note, however, was that even the *solar*-diurnal variations, which are much more accurately determinable than the lunar variations, do not follow the Sunspot curve without considerable irregularities. Comparison should therefore be made between the solar- and the lunar-diurnal magnetic variations, rather than between the latter variations and the Sunspot numbers. It is desirable, moreover, not only that data from several stations should be examined, but that the data should refer to the same period as far as possible. An investigation of adequate scope, conducted along these lines, would be of much value. If the negative conclusion arrived at by Sabine, Chambers and Figee were corroborated, the blow to the suggested theory of the phenomenon would be very serious, and it is well that the point should be cleared up as soon as may be. Also a close comparison of the Sunspot effect on the different periodic components of the solar- and lunar-diurnal variations would afford results of considerable theoretical value.

With a view to a general discussion of the above theory I have had new computations[5] of the lunar-diurnal magnetic variation made for 5 stations, Pavlovsk, Pola, Zikawei, Manila, and Batavia, using observations covering 7 years for each station. Seven "quiet" years were chosen for this purpose, in order to minimize difficulties from magnetic disturbance; a longer series of observations would have been necessary to obtain equally satisfactory data in more disturbed years. The variation of solar activity during the period was not negligible, however, as Table 1 giving the corresponding annual mean Wolfer Sunspot numbers will indicate:

[5] The chief results are given in the papers already cited (see the 1914 paper for the method of reduction). The cost of computation was mainly defrayed by a grant from the Government Grant Committee of the Royal Society. I have also to acknowledge assistance kindly placed at my disposal by the Astronomer Royal and Dr. Schuster.

TABLE 1.

Year	Sunspot Number	Assigned Character	Observatory
1888	7.0	Minimum	Batavia
1889	6.3	Minimum	Batavia
1890	8.4	Minimum	Batavia
....	.....	....	....
1897	28.1	Intermediate	Pa., Po., Z., M., B.
1898	24.6	Intermediate	Pa., Po., Z., M., B.
1899	13.8	Intermediate	Pa., Po., Z., M.
1900	8.8	Minimum	Pa., Po., Z., M.
1901	3.4	Minimum	Pa., Po., Z., M.
1902	5.6	Minimum	Pa., Po., Z., M., B.
1903	22.9	Intermediate	Pa., Po., Z., M., B.

The adopted years for which observations were discussed were 1897-1903, but in the case of Batavia certain of the records were wanting during 1899-1901, and these were replaced by the data for the corresponding years (1888-1890) of the previous 11-year cycle. The letters in the last column of Table 1 indicate the observatories from which data for each of the years were used. The character "minimum" or "intermediate" was assigned to each year, as indicated in the third column, according to the magnitude of the Sunspot number in the second column.

Although the newly-reduced data above-mentioned were designed mainly for other uses, it seemed worth while, in view of the range of solar activity during the period from which they were drawn, to examine how far they could throw light on the question of Sunspot influence upon the lunar-diurnal magnetic variation. The utmost effect to be expected in the present case was but small, since on the most favorable probable theory (that of parallelism with the solar variation) a total variation of only about 30 percent would correspond to the range between Sunspot maximum[6] and Sunspot minimum. Since a small percentage change in the lunar variation would be likely to be least masked by accidental error when the amplitude of the variation was greatest, the present discussion was confined from the outset to the elements and seasons for which the semi-amplitude of the lunar-semidiurnal variation is approximately 1γ (10^{-5} C. G. S.). Also, on account of the shifting phase of the non-semidiurnal components, these were not considered, especially as their ampli-

[6] The Wolfer numbers in maximum years generally amount to 80 or 90.

tudes were generally smaller or less well-determined than those of the semidiurnal components. These other components, however, ought certainly to be considered in any special investigation of the influence of solar activity on the lunar variation.

The semi-amplitude c_2 of the 12-hour component in the lunar variation at the several observatories amounted to about 1γ in 17 cases, the elements and reasons in question being indicated in Table 2. It should be mentioned that the year was subdivided into three seasons, summer being represented by the four months May-August, winter by November-February, and the equinoxes by the intervening four months. The actual semi-amplitudes c_2 and phase angles θ_2 in the various cases will not be reproduced here; they are to be found (in the form of 7-year means) in the paper recently communicated to the Royal Society. In Table 2 only the amplitude-ratios (intermediate÷minimum) and the phase-differences (intermediate−minimum) are given, from the mean results for the 3- or 4-year groups of intermediate or minimum Sunspot years already indicated.

Pursuant to the suggestion already made, the values of c_2 and θ_2 for the contemporaneous solar-diurnal variations were computed, using the monthly mean hourly inequalities published in the records of the 5 observatories. The ratios of c_2 and differences of θ_2 are given in the table alongside the corresponding data for the lunar-diurnal variations. The mean values of the two quantities in the respective cases are given at the foot of the table. In taking the means, however, one set of the lunar and another of the solar numbers were bracketed and omitted because of the very abnormal amplitude-ratios, combined, in the latter case, with a phase-reversal between Sunspot maximum and Sunspot minimum.

The mean amplitude-ratios and also the mean phase-differences are strikingly accordant for the solar and lunar variations, and some of this accordance can be attributed to accident without seriously affecting the support given by the table to the conclusion that the solar and lunar variations show a parallel relationship with the solar activity. A rather surprising feature of Table 2 is that the lunar amplitude-ratios seem, if anything, less irregularly affected by accidental error than the solar values. In only 4 cases do the lunar amplitude-ratios fall below unity. The mean variation of 5 or 6 percent is as much as was to be anticipated from the small range in the Sunspot numbers.

TABLE 2.

Observatory	Element	Season	Amplitude-Ratio (Int./Min.)		Phase-Difference (Int.—Min.)	
			Lunar	Solar	Lunar	Solar
					°	°
Pavlovsk	Declination	Summer	1.02	1.06	+11	− 2
"	Hor. Intensity	"	1.02	1.12	+16	− 1
Pola	Declination	"	0.86	1.05	+ 4	− 1
"	Hor. Intensity	"	1.03	1.24	+16	− 1
Zikawei	Declination	"	1.02	1.13	+ 7	+ 1
"	Ver. Intensity	"	1.00	1.37	− 4	+11
"	Declination	Equinox	1.17	0.89	− 7	+ 3
"	Ver. Intensity	"	0.99	0.92	−10	− 2
"	Hor. Intensity	Winter	[1.55]	0.88	[20]	−17
Manila	Declination	Summer	1.14	1.13	+ 8	− 6
"	Ver. Intensity	"	0.89	0.88	− 3	+ 2
"	Declination	Equinox	1.10	0.93	−16	− 2
"	Declination	Winter	1.14	[1.62]	+ 4	[−180]
"	Hor. Intensity	"	1.28	1.08	−18	+ 2
"	Ver. Intensity	"	0.94	0.89	− 4	+ 9
Batavia	Declination	"	1.23	1.18	− 6	− 5
"	Hor. Intensity	"	1.20	1.07	−10	− 3
Means (excluding bracketed values)			1.064	1.051	−0.8	−0.8

The phase-differences are more irregular than the amplitude-ratios, perhaps, but they indicate that any effect of solar activity on the phase-angles is small (over the given range of Wolfer numbers) in both sets of variations. Both as regards the ratios of c_2 and differences of θ_2, I think that stress cannot be laid on detailed differences suggested by forming sub-groups of numbers from Table 2, according to observatory, element or season. It does appear to be sufficient, however, taken as a whole, to afford a well-grounded hope that a fuller investigation of the Sunspot effect, based on data specially chosen for the purpose, will not prove antagonistic to the suggested theory of the lunar-diurnal magnetic variations.

ROYAL OBSERVATORY, GREENWICH.

ON RECENT SECULAR VARIATION OF THE MAGNETIC ELEMENTS IN AND NEAR JAVA.

By W. Van Bemmelen, *Batavia*.

In the course of the year 1916, my colleague, Dr. J. Boerema, and I had the opportunity of repeating observations at most of the stations in Java visited during the magnetic survey of the years 1903-1907.[1] Though we intended also to revisit stations in the outer parts of the Archipelago, various circumstances have thus far prevented us from doing so, and it is not certain that this will be possible in the next few years. Accordingly I think it best to give a preliminary report of the work done, especially since the period considered here (1905-1916) coincides with that of recent surveys covering nearly the whole globe. Only one station at a considerable distance from Java could be visited, viz., Seroetoe, situated between the islands of Billiton and Borneo.

Observations have been made with the same instruments and following the same methods as before, but at most stations it was impossible to occupy exactly the same spot; in the table of results such stations are

Table of Results.

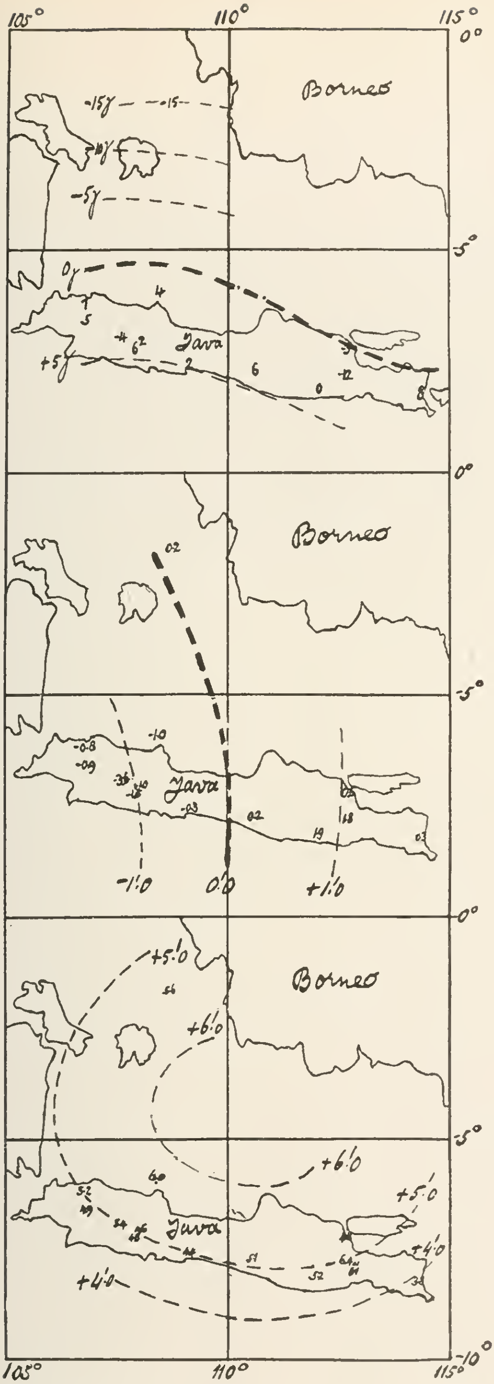
Station	Latitude	Longitude East of Gr.	Magnetic Elements 1916.5			Annual Rate of Secular Variation 1905.5—1916.5		
			Declination	Inclination	Hor. Int.	Decl'n	Incl'n	Hor. Int.
	° ′	° ′	° ′	° ′	c.g.s.	′	′	γ
Batavia	6 11 S	106 50	0 46.0 E	31 38.1 S	.36700	−0.8	+5.2	+ 1
Buitenzorg	6 35 S	106 47	0 26.0 E	32 18.0 S	.36558	−0.9	+4.9	+ 5
Bandoeng*	6 55 S	107 36	0 07.6 E	32 58.2 S	.36632	−3.6	+5.4	− 4
Boompjes Island	5 56 S	108 23	0 59.2 E	30 47.0 S	.36909	−1.0	+6.0	+ 4
Tjibatoe	7 06 S	107 59	0 51.9 E	33 16.1 S	.36431	−1.3	+4.6	+ 2
Garoet*	7 13 S	107 54	0 26.3 E	33 26.1 S	.36518	−1.5	+4.8	+ 6
Maos*	7 37 S	109 08	0 58.8 E	33 47.6 S	.36586	−0.3	+4.4	+ 2
Ngoepit	7 40 S	110 36	0 59.9 E	33 26.7 S	.36443	+0.2	+5.1	+ 6
Blitar*	8 06 S	112 10	1 39.6 E	34 23.7 S	.36201	+1.9	+5.2	0
Lawang	7 50 S	112 41	1 11.0 E	33 22.8 S	.37080	+1.8	+6.4	−12[2]
Soerabaja*	7 12 S	112 44	1 36.6 E	32 10.9 S	.36975	+0.6	+4.8	− 3
Poespo	7 50 S	112 54	....	32 46.2 S	......	.....	+0.1[3]	.....
Tosari	7 53 S	112 54	....	34 25.3 S	......	.....	+6.1	.....
Banjoewangi	8 12 S	114 23	1 36.5 E	33 51.2 S	.36500	+0.3	+3.8	+ 8
Seroetoe Island*	1 43 S	108 42	1 36.3 E	22 27.5 S	.37136	+0.2	+5.6	−15

* Previous station not reoccupied exactly.

[1] Appendix I to Observations made at the R. M. and M. Observatory at Batavia, vol. XXX, 1907.

[2] This abnormal rate no doubt is connected with the abnormal value of the horizontal intensity, which points to a local disturbance of the field of 300 to 400γ.

[3] Cause of abnormai value probably local.



HORIZONTAL INTENSITY

EASTERLY DECLINATION

SOUTHERLY INCLINATION

LINES OF AVERAGE EQUAL ANNUAL CHANGE OF THE MAGNETIC ELEMENTS IN THE DUTCH EAST INDIES FOR JANUARY 1, 1911, AS BASED ON OBSERVATIONS, 1905-1916.

marked by an asterisk. Reduction to the epoch 1916.5 was possible only by calculating preliminary values of the yearly means of the magnetic elements for Batavia; thus the results given here are also preliminary. These yearly means have been calculated from the weekly absolute determinations made in the semester April-September, 1916, reducing them to daily means by use of daily variations as found in the year 1904, a year lying near a sunspot-maximum, as is the case with the year 1916.

For the period 1876-1905 it was possible to draw curves of equal annual rate of secular variation, and when plotting the above-found values, corresponding curves may be drawn, notwithstanding the fact that these latter values would scarcely, if at all, warrant the construction of such curves without the guidance of the former set. Comparing the two sets it is seen at once that for the horizontal intensity the line of no-variation has not moved much; on the other hand, in the regions to the north and south of it, the variation has reversed its sign. In Java the horizontal intensity increased between 1848 and 1876, but at Batavia from 1884 (when regular observations started) on, the intensity was decreasing. Recently it changed sign again, as is evident from the yearly means.

Year	Hor. Int. at Batavia	Year	Hor. Int. at Batavia
	c. g. s.		*c. g. s.*
1902	.36717	1909	.36654
1903	691	1910	660
1904	686	1911	664
1905	668	1912	683
1906	685	1913	690
1907	678	1914	686
1908	676	1915	. . . .[4]
		1916	700[5]

However, some doubt about the minimum epoch remains, as in the year 1910 it was necessary to change the instrumental constants used for the magnetic theodolite, involving an abrupt change of 28γ (*cf.* Observations Batavia vol. XXXI, 1908). This amount I have distributed over the years 1902-1908 (*cf. l. c.*). Notwithstanding this uncertainty, it is pretty sure that the secular variation changed sign in the year 1909; also, that all over Java and the surrounding regions a reversal occurred.

Unlike the curves for the intensity, those for declination point to a regular westward movement. For the periods 1876-1905 and 1905-1916, the zero-line of secular change crossed the parallel of Batavia in longitudes 114.°5 and 110° E., respectively; therefore assuming constant progression, Batavia should be reached in the year 1918. Indeed the yearly means found point to an early reversal.

[4] Not yet computed.

[5] Preliminary.

Year	Declination at Batavia	Year	Declination at Batavia
	° ′		° ′
1902	1 02.40 E	1909	0 49.51 E
1903	0 59.69 E	1910	0 48.71 E
1904	0 57.51 E	1911	0 47.67 E
1905	0 54.98 E	1912	0 47.29 E
1906	0 54.11 E	1913	0 46.44 E
1907	0 52.21 E	1914	0 46.16 E
1908	0 50.74 E	1915	..........[6]
		1916	0 46.0 E[7]

No such reversal is met with in the inclination. At Batavia the annual rate of change diminished from 9.′0 during the period 1876-1905 to 5′0 during the recent period 1905-1916, and all over Java and the surrounding regions decrease is evident.

From the results for declination and inclination, it follows that at Batavia, from the middle of the preceding century up to now, the north end of the needle has moved in a counter-clockwise direction; but, as its present westward motion seems to be coming to an end, and the upward motion, though slowing down, has not yet ceased, the regular secular swinging of the needle presumably will suffer a disturbance in the near future.

[6] Not yet computed.
[7] Preliminary.

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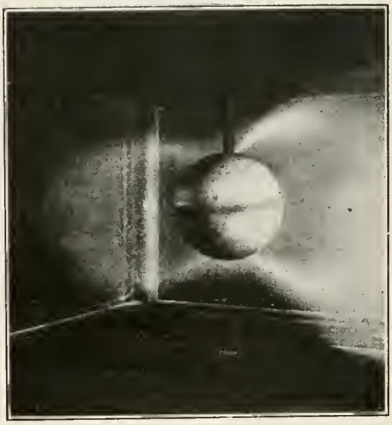

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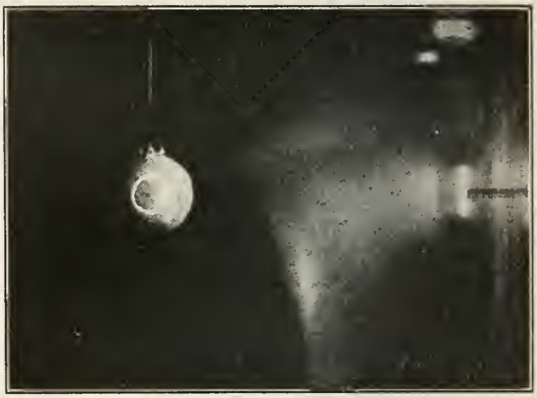

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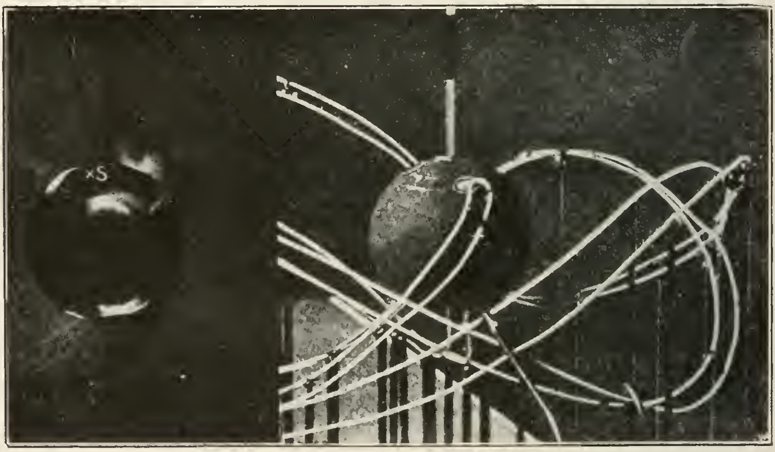

b

CORPUSCULAR THEORY OF THE AURORA BOREALIS

Terrestrial Magnetism
and
Atmospheric Electricity

VOLUME XXII SEPTEMBER, 1917 NUMBER 3

CORPUSCULAR THEORY OF THE AURORA BOREALIS.
(CONCLUDED)[16]

BY CARL STÖRMER, *Kristiania.*

When γ further decreases and tends towards a certain value between — 0.93 and — 0.94, ϕ_γ decreases to $-\infty$, that is to say, we obtain trajectories that go around the globe in waves an unlimited number of times before reaching the origin. From this we conclude that from a given point in space there are in general a series of distinct trajectories going to the origin. They correspond to a series of directions D_γ issuing from the point M_γ, and which we shall term *distinguished directions*; their number will vary with the position of the point M_γ; if that position changes, some of the directions may vanish and others appear. The trajectories going to the origin from the side where z is negative, are symmetrical to the others with respect to the XY-plane. (On Pl. I, *d* [16] is given a model of trajectories to the North Pole and South Pole, coming from points of emanation lying near each other. Their distances from the origin are much less than in the models, Pl. I, *b* and *c* [16].)

9.—APPLICATION TO BIRKELAND'S EXPERIMENTS.

The foregoing results will now be applied to some of Professor Birkeland's experiments. Plate II, *a*, reproduces a very beautiful experiment made by him,[17] in which a mass of cathode rays are sent from the right side towards the magnetized globe. The characteristic form of the region Q_γ, shown in Fig. 2 [16], can be seen in the experiment, on the right, corresponding to γ about — 0.3, and on the left to γ about — 0.8; the rays enclosed in the region Q_γ, for $\gamma =$ — 0.8, are turned around the Z-axis a greater angle than those corresponding to γ about — 0.3, as known from the trajectories through the origin.

[16] See *Terr. Mag.*, March, 1917, pp. 23-34.

[17] The Norwegian Aurora-Polaris Expedition, 1902-1903, vol. I, second section, p. 712.

Another very interesting coincidence of theory and experiment is seen in Plate II, *b*, where the patches on the magnetized globe, caused by precipitation of cathode rays, are compared with the calculated trajectories[18]; the wire model, of which the illustration shows a part only, has already been given in Plate I, *d* [16]. The entire zone of precipitation for all the calculated trajectories given in Fig. 4 [16], is shown very beautifully in Professor Birkeland's experiments,[19] Plate II, *c*. In our calculations, however, the zone has been turned a certain angle, because the points of emanation of the trajectories have a relatively much greater distance from the globe than in Birkeland's experiment. The rotation is also in the right direction, as will be understood by making a comparison between the two tables [20] of corresponding values of γ, ψ_γ, and ϕ_γ. For the

[18] *Iaem*, first section, p. 159.

[19] *Idem*, second section, p. 598.

[20] See footnote 16.

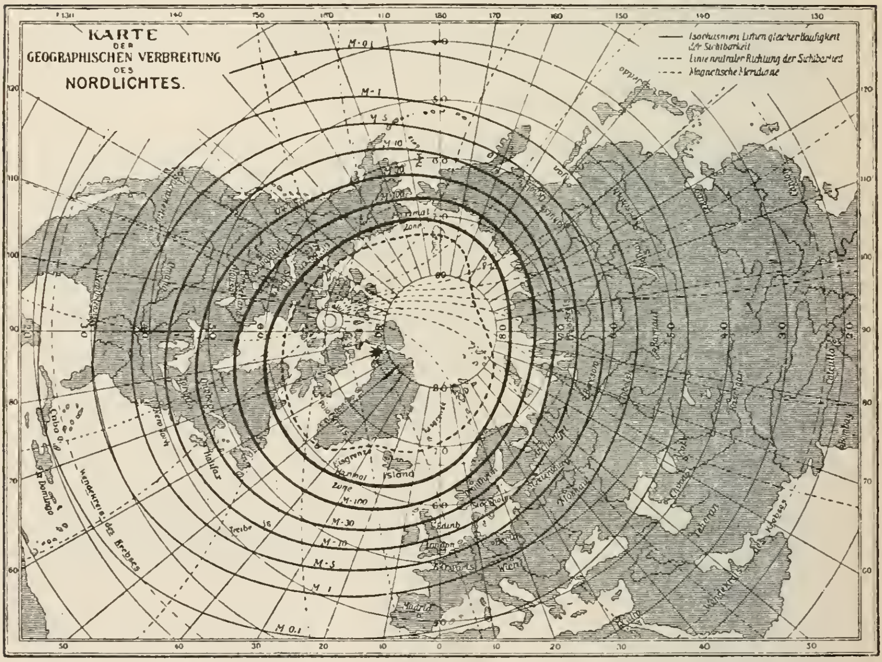

Fig. 6.—Map showing the Geographic Distribution of Polar Lights. (The star indicates approximately the point of intersection in 1900 of the Earth's Magnetic Axis with the Northern Hemisphere.)

theoretical explanation of a large series of other remarkable experiments I refer to a paper published in 1911.[21]

10.—FIRST APPLICATION TO AURORA POLARIS.

As already explained in § 2, we consider for our purposes the Earth's magnetic field to be equivalent to that of an elementary magnet at the center of the Earth. For 1900 the magnetic moment, M, of this assumed elementary magnet was about 8.3×10^{25} C. G. S. units; its magnetic axis, the same as that of the Earth, in 1900 cut the Northern Hemisphere approximately in latitude 78°.5 and in longitude 70° West of Greenwich (see Fig. 6). The "north end" of this magnetic axis corresponds to the "south end" of the elementary magnet.

For the dimensions of the trajectories, our unit of length in cm., $c = \sqrt{M / H\rho}$, has to be found; M is known, but as regards the product $H\rho$, for the corpuscles in question, we can only make assumptions. In my Geneva paper of 1907 I calculated c for cathode rays, β rays and α rays of radium. The results were:

	$H\rho$	c in km.
Cathode Rays	108	8,900,000
	543	4,000,000
β Rays	1,801	2,200,000
	4,524	1,400,000
α Rays	291,000	170,000
	398,000	146,000

The dimensions of the regions Q_γ are therefore immense as compared with those of the Earth (see Fig. 7).

Figure 7 represents the various shapes of the sections of a series of regions Q_γ in the vicinity of the origin. The scale, which is much larger than that for Fig. 2, is marked on the R-axis, $\sqrt{M / H\rho}$ being taken as the unit of length. The regions Q_γ (white), in order to avoid confusion, are not continued as far as the origin. The five dotted circles (Fig. 7) indicate the relative size of the Earth as compared with the spaces Q_γ for various kinds of corpuscles. The inner circle corresponds to cathode rays, where $H\rho = 315$, the next two circles to β rays, where $H\rho = 2{,}891$ and $4{,}524$, and the two outer circles to α rays, where $H\rho = 291{,}000$ and $398{,}000$. The regions of the Earth to which the corpuscles from the Sun can not

[21] Sur une classe de trajectoires remarquables dans le mouvement d'un corpuscule électrique dans le champ d'un aimant élémentaire. *Archiv for Mathematik og Naturvidenskab*, vol. XXXI, 1911.

Fig. 7

come are now readily found; we remember that for γ between $-\infty$ and -1, the regions Q_γ were closed, and consequently those regions of the Earth coinciding with these regions can not receive corpuscles. As shown in Fig. 7, we thus obtain as regions of the Earth, where the corpuscles can not enter, those comprising the tropics and limited by two circles around the magnetic axis, one in the Arctic and the other in the Antarctic zone. The angular radius Ω of each of these circles can now be found with sufficient accuracy from formula (1) if we put $\gamma = -1$, and r_0 equal to the distance, $\triangle$, from the center of the Earth to the regions of the aurora. We then obtain $\sin \Omega = \sqrt{2\triangle}$. Here $\triangle$ is measured with $c = \sqrt{M\ H\rho}$ as unit of length. If we measure $\triangle$ in cm., and if it is equal to D cm., we obtain

$$\sin \Omega = \sqrt{\frac{2D}{c}} \qquad (2)$$

This formula determines the southern boundary of the aurora-borealis region, and the northern boundary of the aurora-australis region.

For cathode rays, I found Ω between 2° and 4°, and for β rays between 4° and 6°. In the case of α rays, however, the numbers were between 16° and 19°. Now the zone of maximum frequency of auroras has an angular radius of about 23°. *We here meet with the first objection to the theory that the aurora is due to negatively-charged particles—the resulting radius of the aurora-zone is far too small.* In the case of positively-charged α particles, however, we obtain a zone that is not very different from the one observed. This important question will be discussed again later on.

In Figs. 8 *a* and 8 *b* are seen the theoretical boundaries of the aurora-zones for cathode rays, β rays, and α rays, and also two dotted circles of angular radius 23°. The northern dotted circle is based on observations, whilst the southern one is drawn symmetrically to the former with respect to a plane through the center of the Earth and normal to the magnetic axis.

The next limitation of the aurora-zones to aurora-belts appears when we apply the results concerning the trajectories through the origin; for if, as in my Geneva paper, we assume that $H\rho$ lies between 100 and 400,000, it will be seen that only those corpuscles with trajectories situated in the vicinity of those reaching the origin can reach the Earth; the others return into space. Now the angle between the plane normal to the Earth's magnetic axis and the line from the Earth to the Sun, varies between — 35° and + 35°, and,

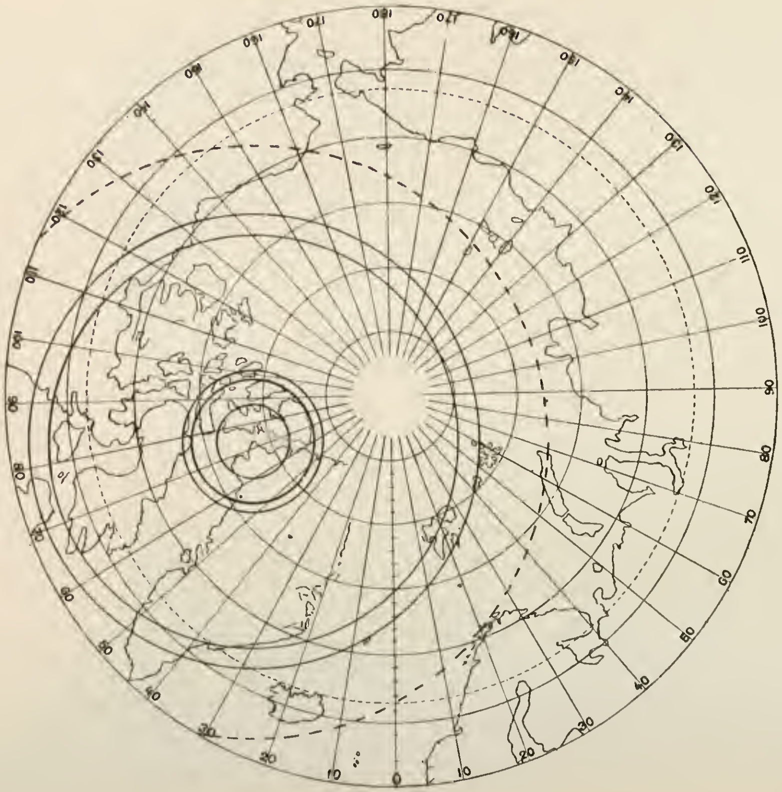

Fig. 8a.

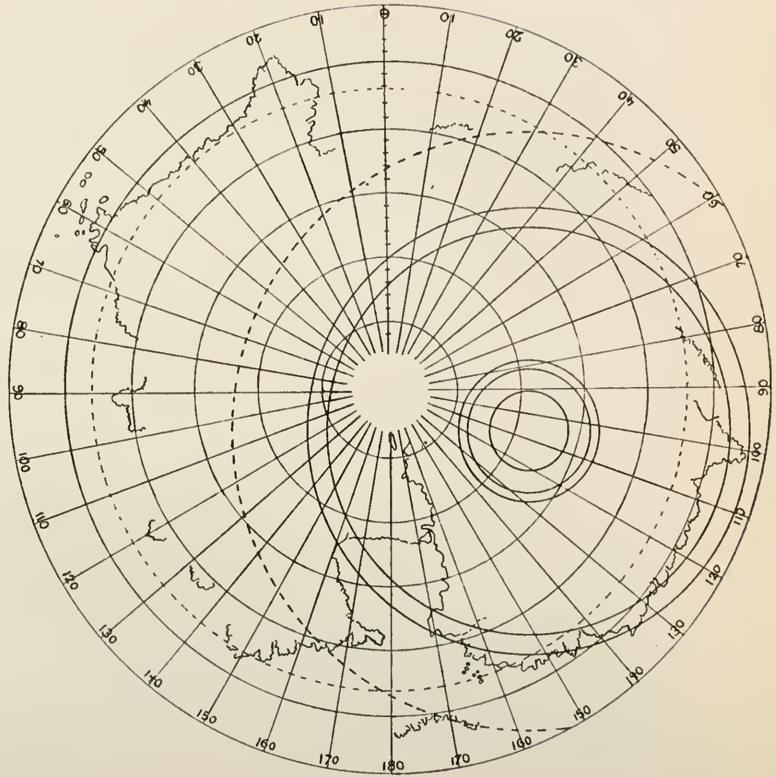

Fig. 8b.

therefore, trajectories coming from points situated outside this interval of direction must be excluded.

We thus find from the tables (§ 8) that trajectories—and, consequently, regions Q_γ, where γ lies between 0 and -0.2—must be discarded. We thus obtain an inner limitation towards the magnetic axis of the aurora-zones, and we have *in this way found a theoretical explanation of the aurora-belts.*

The breadth of the belts will be reduced if we take into account the auroras seen only during the night. It is then necessary to exclude all the trajectories that meet the Earth at places where the Sun is above the horizon, i. e., trajectories for which γ lies between -0.2 and -0.5, approximately. The inner limitation of the aurora-belts can thus be given by the formula (putting $c = \sqrt{M / H\rho}$):

$$\sin \omega = \sqrt{\frac{D}{c}} \tag{3}$$

where ω is the angular radius of the inner limiting circle.

11.—FURTHER APPLICATION TO THE AURORA, ARCS AND CURTAINS.

The further application of the theory of trajectories through the origin now affords a good explanation of a series of characteristic features regarding the aurora-displays. Let us assume that corpuscles are sent out from a point of the Sun's surface into space in all directions, and let us suppose that $H\rho$ is the same for all these corpuscles, and lies between 400 and 400,000. As stated before, only the corpuscles with a direction of emanation nearly tangent to a trajectory through the origin will reach the Earth, the others passing again into space. Let us also as above (see Fig. 5), call the directions tangent to the trajectories through the origin *distinguished directions.* Corpuscles that proceed in these directions will go farthest down in the atmosphere, whilst others, with directions of emanation differing slightly from distinguished directions, will describe spirals like that in Fig. 3 (p. 31), and pass out again into space if not absorbed in the atmosphere.

We saw above, that the distribution and number of distinguished directions vary enormously according to the relative position of the point of emanation with respect to the axis of the Earth. Now this position changes continually because the magnetic axis follows the motions of the Earth, and, consequently, the conditions for occurrence of the aurora must vary considerably with time, a circumstance that accords well with the *sudden and variable char-*

acter of aurora-displays. This may also explain the fact frequently observed—that the aurora occurs on two consecutive days almost at the same hour; in fact, the relative position of the point of emanation and the Earth's magnetic axis is very nearly the same after the lapse of 24 hours.

As the point of emanation follows the rotation of the Sun, we have another well-known period of about 27 days between the two consecutive passages of a Sun-spot. In those cases where the Sun-spot does not give rise to a new aurora the next time it passes, we may give the explanation that it is due to the non-coincidence of the directions of emanation and the distinguished directions; in fact, a slight difference in the relative positions can cause the disappearance of the distinguished directions that existed at the first passage. We shall now see *how the formation of arcs and curtains is a natural consequence of the corpuscular theory.*

Let us assume that a beam of corpuscles (with the same $H\rho$) emanates from a surface on the Sun, and that it reaches the Earth's atmosphere and produces an aurora. The constant γ for the different trajectories of the beam is given by the formula

$$2\gamma = R \sin\theta - \frac{R^2}{r^3} \qquad (4)$$

where R and r are coordinates of the point from which the trajectory starts, and θ is the angle between its tangent at that point and the plane through the magnetic axis of the Earth. It is clear that if we choose the *same* γ for all the trajectories, the beam will consist of almost parallel rays. All the trajectories will then be confined to the interior of the corresponding region Q_γ and, consequently, the aurora also. Now near the Earth this region Q_γ is the extremely narrow space between two surfaces of revolution, with the magnetic axis as axis (see Fig. 7). The aurora will therefore appear in the regions of the atmosphere lying within this narrow space; the said regions extend all around the Earth with the magnetic axis in the middle, one in the Arctic and another in the Antarctic. According to computation, its thickness is:

For cathode rays,	between	3	and	20	meters
" β	"	"	50	"	150	"
" α	"	"	9,000	"	13,000	"

Therefore, as already pointed out in my paper "Sur le mouvement d'un point matériel, etc., *Videnskabsselskabets Skrifter*, 1904", the

rays of the beam spread out in this region will give rise to the phenomena of light that, according to circumstances, we call an arc, or a curtain.

In my Geneva paper of 1907 I computed a special case in which was studied the spreading out of an originally cylindrical beam into an aurora-curtain, very thin and several kilometers long. This fan-like extension will be readily understood if we again study the tables of corresponding values of γ, ϕ_γ, ψ_γ, and α_γ, given in § 8. For the subsequent application, let us take the second table and choose $\Omega = 24°$. We then obtain Fig. 9. For each ψ_γ, i. e., for each value of the angle between the direction from the Earth to the Sun and the plane normal to the magnetic axis, we thus find the "*magnetic azimuth*," ϕ_γ, of the point of precipitation relative to the Sun

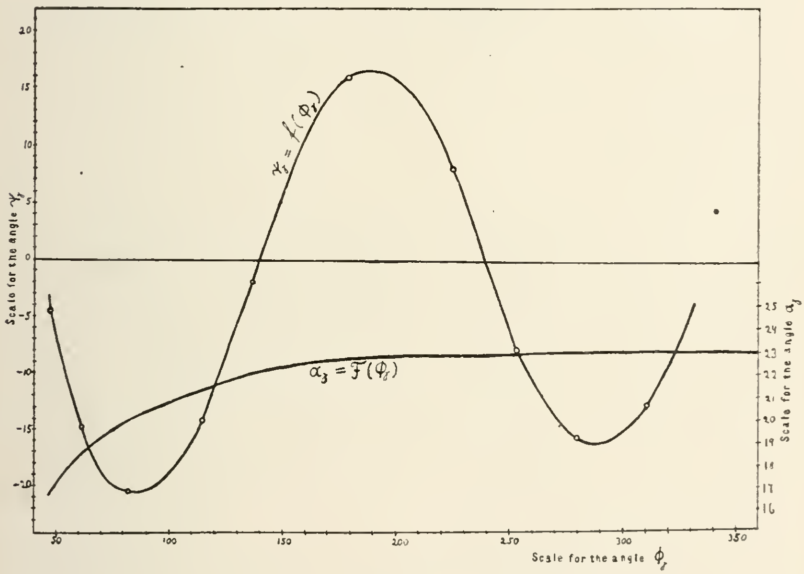

Fig. 9

and its angular distance from the point M, where the magnetic axis cuts the northern hemisphere of the Earth. For the point M, ψ_γ is equal to the height of the Sun above or below the horizon. The diagram gives us the following values:

2

	1st Precipitation		2nd Precipitation		3d Precipitation		4th Precipitation	
ψ_γ	ϕ_γ	a_γ	ϕ_γ	a_γ	ϕ_γ	a_γ	ϕ_γ	a_γ
°	°	°	°	°	°	°	°	°
16	......	....	185	22.8	195	22.8	......	....
14	......	....	170	22.6	208	22.8	......	....
12	......	....	163	22.5	215	22.9	......	....
10	......	....	159	22.4	220	23	......	....
8	......	....	154	22.3	225	23	......	....
6	......	....	150	22.2	229	23	......	....
4	......	....	146	22.2	232	23	......	....
2	......	....	143	22.1	235	23	......	....
0	......	....	140	22.1	239	23	......	....
− 2	......	....	137	22	242	23	......	....
− 4	47	16.7	133	21.9	246	23	331	23.1
− 6	50	17.1	130	21.8	250	23	327	23.1
− 8	52	17.3	126	21.7	254	23	322	23.1
−10	54	17.5	122	21.5	259	23	317	23.1
−12	57	17.9	119	21.4	265	23.1	312	23.1
−14	60	18.3	115	21.3	272	23.1	305	23.1
−16	64	18.6	110	21.1	282	23.1	282	23.1
−18	68	18.9	104	20.9	......	......	....	....
−20	77	19.5	93	20.4	......	......	....	....

If we place all the points of precipitation according to this scheme, we obtain the different positions of these points for various values of the height of the Sun above the horizon at the point M. We thus obtain Figs. 10 and 11. On inspecting these figures we see that the variation in position is *very great* near the values − 20°, 16° and − 16°, corresponding to the *maxima or minima of* ψ_γ *considered as a function of* ϕ_γ. *Rays of a corresponding beam will therefore undergo a fanlike extension into a curtain*, as seen in detail in my Geneva paper. (See also my essay in the Inaugural lectures of the Rice Institute.)

Analogous considerations may be made for every series of trajectories through the origin, when γ lies between − 0.93 and − 1. Such series, however, have not yet been computed.

The remarkable fact that we have several aurora-curtains behind one another on one and the same occasion is also capable of explanation. There may be two reasons. If the surface of emanation sends out corpuscles with velocities of a finite number of distinct values that differ only slightly from each other, our unit of length will differ for the different kinds of corpuscles, and therefore also the distance of the curtain from the magnetic

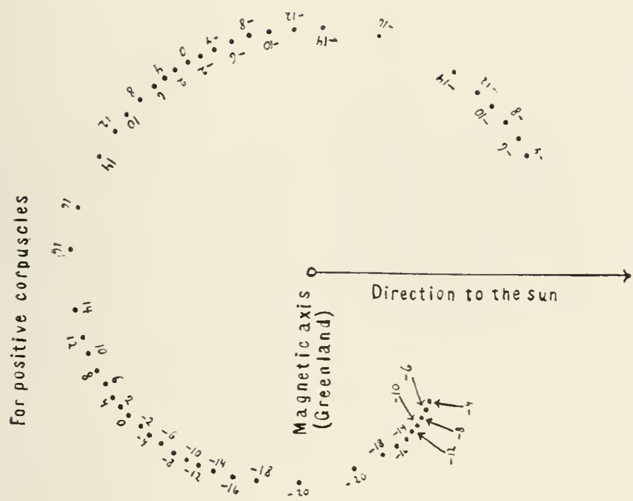
For positive corpuscles
Magnetic axis
(Greenland)
Direction to the sun

FIG. 11


For negative corpuscles
Magnetic axis
(Greenland)
Direction to the sun

FIG. 10

axis; we shall obtain a "spectrum" of curtains one behind the other. And even with the same kind of corpuscles we may obtain a series of curtains. Let us for instance assume that the direction of emanation corresponds to a value like γ^*, which is the limit of a series of values of γ corresponding to trajectories of the above-mentioned kind (see § 8). We remember that corpuscles following these trajectories go around the Earth an increasing number of times before reaching the North or South Pole, when γ tends towards the limit γ^*. Then the corpuscles from the surface of emanation will be subject to several cases of fan-like spreading for values of γ which differ very little from each other. A series of curtains will thus appear all around the aurora-zones to the north and south, and when they occur in the same meridian they will appear one behind the other.

The situations giving rise to curtains and to series of curtains are very transient, because the magnetic axis of the Earth rotates around the axis of rotation in the course of the diurnal motion. This is also in accordance with the observed fact that these beautiful displays come suddenly and last only a few minutes.

12.—SITUATION OF THE AURORA-BELTS AND ACTION OF THE CORPUSCULAR FIELD.

As was pointed out at the beginning of this paper, the theory here given is only a first approximation to reality. It is therefore remarkable to observe how many particularities of the aurora-phenomena are already capable of explanation. But there are also facts that do not agree well with the theory.

The chief unexplained fact is *the situation of the belts of maximum frequency of the aurora borealis*. We have seen that the outer border had an angular distance, Ω, from the magnetic axis, which, as given by formula (2), was about 6° for β rays (corresponding to $H\rho = 5{,}000$), and about 18° for α rays of radium. The real value for the aurora-belt, on the contrary, is about 23° (corresponding to $H\rho$ about 1,000,000), and sometimes, during magnetic storms, the aurora goes even much farther south. In my Geneva paper of 1907, I already admitted the possibility of the corpuscular rays that correspond to large Sun-spots and brilliant auroras having a much larger value for $H\rho$ than those corresponding to auroras in the maximal zone; but I did not pay much attention to that side of the question. It seemed possible that if we took into account the more complete Gaussian expression for the Earth's magnetic field, with

the higher harmonic terms included, we might perhaps get the real situation of the aurora-belts. The work of testing this was an extremely laborious and tedious task. I had first to compute tables and draw diagrams necessary for selecting the values of the magnetic force at every point of space outside the Earth; direct calculation would be impracticable because the expression of each component of the magnetic force contained about 50 terms. I had then to calculate the lines of force, and finally the trajectories. These computations were published in my Geneva paper of 1911-1912; the results, however, were negative, being as follows: *It seemed probable, but could not be decided with certainty, that the consideration of the Gaussian expression, including all terms known, could not explain the real situation of the aurora-belts of maximum frequency.**

On the other hand, Professor Birkeland published the idea [22] that the situation of the aurora-belts was due to negatively-charged corpuscles, for which $H\rho$ had the extremely large value of 1,000,000 to 10,000,000 [23] (corresponding to a velocity only a few meters inferior to that of light), and a penetrability so great that the aurora-rays could go almost down to sea-level. But this interesting explanation has the drawback that direct observations have not yet proved the existence of corpuscular rays of such unusual penetrability.

In my Geneva paper of 1911-1912, I proposed another explanation, which would also provide a reasonable hypothesis for the fact that, during magnetic storms, the aurora borealis can extend much farther south than at ordinary times. We have seen that the theory leads to a large bulk of corpuscular rays bending around the Earth on the afternoon-and-night side, as shown in the wire model, Plate I, *a*. It seemed probable that such a bulk of corpuscular rays, and even more so a closed corpuscular ring, might have an influence on the corpuscles coming from without, and affect the situation of the theoretical aurora-belts.

The general problem being too difficult, I merely studied the action of a corpuscular ring, assuming this to be equivalent to a galvanic current. The detailed investigation will be found in my Geneva paper of 1911-1912. The principal result was: *A cor-*

* This conclusion applies only to the portion of the Earth's magnetic field arising from *internal* causes. It does not take into account a possible effect from the appreciable part of the field, to be ascribed to external causes, which is especially pronounced during magnetic storms.—ED.

[22] *Comptes Rendus*, Paris, 24 janvier, 1910.

[23] The Norwegian Aurora-Polaris Expedition, 1902-1903, second section, p. 595, 1913.

puscular ring can draw the aurora-belts, even for cathode rays, from their theoretical positions down to the real position of the zones of maximum frequency of auroras ($\Omega = 23°$), *without exercising greater magnetic effect on the Earth than about* .00030 C. G. S.

Another effect of such a ring is to concentrate the aurora-zones of different kinds of corpuscles in one belt corresponding to $\Omega = 23°$, *which may perhaps explain the occurrence in this belt of aurora-displays of very different altitudes;* if so, all conclusions relative to the nature of the aurora-corpuscles, which are based on the angular distance of the aurora from the magnetic axis, will be illusory.

Perhaps the most striking consequence of this theory is that if the increasing strength of the corpuscular ring brings the aurora still further away from the magnetic axis, the magnetic effect observed on the Earth increases rapidly until it attains the high values observed during magnetic storms; e. g., the corresponding values of Ω and the action H, in C. G. S. units, of the corpuscular ring are:

Ω	30°	35°	40°	45°	50°
H	.0014	.0032	.0066	.0120	.0190

We thus have an explanation of the fact that *auroras seen so far from the magnetic axis (for instance in Central Europe) are always accompanied by magnetic storms.* For details, we must refer to the above-mentioned Geneva paper of 1911-1912.

13.—ACTION OF A MAGNETIC FIELD AROUND THE SUN.

Another circumstance that may modify certain conclusions of the theory is the possibility of *a magnetic field around the Sun.* Already the form of the corona-streamers seemed to indicate such a magnetic field, and its existence must now be considered proved, after Hale's fundamental researches on the general magnetic field of the Sun. The effect upon the theory of the aurora will then consist chiefly in a modification of the directions, ψ_γ, from which the corpuscles forming auroras come; for if the corpuscle must first move in the magnetic field of the Sun, its trajectory may have many different forms, and will be nearly straight only when at a great distance from the Sun. The application of the tables in § 8 had therefore to undergo modifications. Instead of a direction corresponding to a certain value, ψ_γ, we have to take some other direction situated within a certain cone around this direction, as if the Sun itself were much larger. An exact computation would require

immense labor, for we should first have to find the trajectories in the Sun's magnetic field, and then the corresponding trajectories in the magnetic field around the Earth.

Even the possibility of *an electrically-charged Sun* can be taken into consideration. The modified equations of motion of the corpuscle will be found in my essay in the Inaugural Lectures of the Rice Institute. The consequences, according to Professor Birkeland, appear to be of importance in questions of cosmogony.

14.—ABSORPTION OF THE CORPUSCLES IN THE ATMOSPHERE.

Before concluding this general view of the corpuscular theory of the aurora, mention must be made of *the laws of absorption of corpuscular rays in the atmosphere.* In fact the observed lower limit of the corpuscular rays affords us very valuable information respecting the corpuscular rays which come from without downwards into the atmosphere, and which, in being absorbed, produce the luminous effect that we call aurora.

With regard to negatively-charged corpuscles forming cathode rays and β rays of radium, Lenard published a very interesting formula of absorption.[24] He supposed, like Birkeland, that the beams in the aurora-curtains are formed by negative corpuscles following lines of magnetic force. If I_0 is the intensity of the beam in space outside the atmosphere, and I its intensity at a height of h cm. above the Earth's surface, then Lenard gives the formula

$$\log \text{nat} \left(\frac{I_0}{I}\right) = \frac{a}{b \cos \theta}\, e^{-bh} \qquad (5)$$

where $b = 0.1238 \times 10^{-5}$, and θ is the angle between the line of force and the vertical; a is a constant depending upon the nature of the corpuscular ray. In developing this formula, Lenard assumed that the composition of the atmosphere is the same at all latitudes, and took a mean temperature for the whole layer. He then obtained the following diagram (Fig. 12) for the absorption of negative rays.

Amongst other consequences, Lenard pointed out that auroras observed at an altitude of more than 300 km. prove the existence at that height of very light gases, e. g., helium and hydrogen. This view is in accordance with the conclusions of Hann and others, who have calculated the composition of the air at different altitudes, and have found a deep layer of almost pure hydrogen at an altitude of more than 100 km.

[24] Ueber die Absorption der Nordlichtstrahlen in der Erdatmosphaere. *Sitz.-ber. d. Heidelberger Ak. d. Wiss.*, 1911.

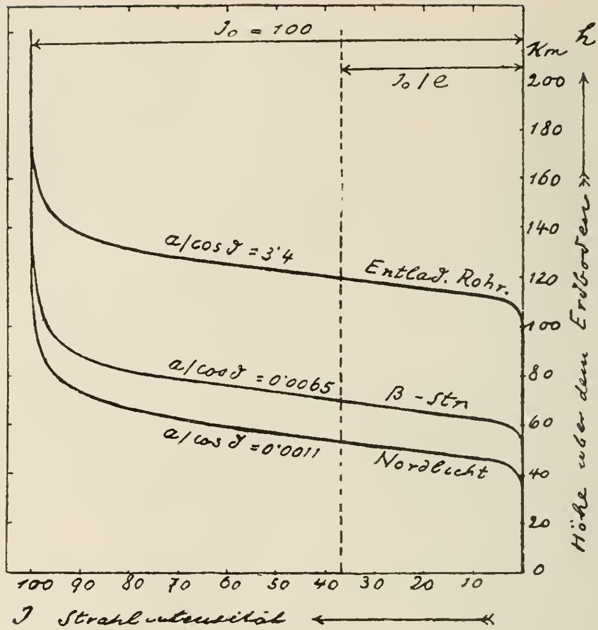

FIG. 12.—Atmospheric Absorption of Negative Rays.

In my Geneva paper of 1911-1912, I took up the calculation of the absorption of corpuscular rays when the temperature and composition of the air vary as we ascend. The results for various assumptions are given in that paper. In all cases we first obtain a slow absorption in the hydrogen atmosphere—down to about 100 km.—and then a rapidly increasing absorption for the last few km.; the first corresponds to the faint and long aurora-rays, and the second, to the luminous lower border of the aurora-curtains. The study of the long and faint aurora-rays in the hydrogen-layer also afforded a measure of the probable temperature in that layer; it was found to lie between — 150° and — 200° C.

As regards *positively-charged corpuscles*, computations have been made by L. Vegard,[25] and very interesting applications to the aurora were made. He studied how far down in the atmosphere α rays can descend under various assumptions relative to the composition and pressure of the air. He found that altitudes of aurora between 70 and 300 km. agree with the α-ray theory, if we assume that the α rays have a velocity of the same order as those observed in the case of α rays emanating from radioactive substances.

In a subsequent paper we will compare the results of the aurora-borealis expedition with the above-given corpuscular theory.

[25] On the Properties of the rays producing Aurora Borealis, *Phil. Mag.* for Feb., 1912, and particularly a paper with the same title published in 1910 in *Archiv for Mathematik og Naturvidenskab*, Kristiania, vol. XXXI.

PULSATIONS MAGNÉTIQUES À ZI-KA-WEI ET À LU-KIA-PANG.

PAR J. DE MOIDREY, S.J.

Nous relevons les pulsations depuis 1896. Il peut paraître temps de faire un court résumé de ces mesures. Il aidera au moins à compléter les travaux du Dr. W. van Bemmelen sur ce sujet.

Nous entendons par pulsations des oscillations très petites et de période, comme d'amplitude, sensiblement constante. Pour une étude statistique il est nécessaire que la vitesse de l'enregistrement soit constante, et c'est notre cas, que les photographies soient également nettes, ce que malheureusement nous ne pouvons prétendre avoir bien réalisé, et enfin que la sensibilité soit aussi constante. Ce dernier point nous force à diviser notre série en trois périodes, celle de Zi-ka-wei, de 1896 à 1908, où la sensibilité était environ 0,000170; la première de Lu-kia-pang, de 1908 à 1912, avec sensibilité 0,000145; et la période actuelle, de 1913 à 1916, avec sensibilité 0,000060. A Zi-ka-wei, nous ne notions pas la rapidité des pulsations. Actuellement nous mesurons la durée de chaque série de pulsations, et le nombre d'oscillations durant ce temps est compté. La vitesse étant sensiblement constante, nous en déduisons la période et c'est le meilleur moyen comme le plus rapide.

D'après leur période nous divisons les pulsations en trois groupes que nous appelons *rapides*, au-dessous de $1^{m},5$ (en fait nous ne descendons pas au-dessous de $1^{m},0$), *moyennes*, de $1^{m},5$ à $1^{m},9$ et *lentes*, de $2^{m},0$ à $2^{m},5$, limite que nous nous sommes fixée. En fait les pulsations plus lentes que nous négligeons, ont à première vue un autre air même sans qu'on apprécie leur rapidité.

A certaines époques aussi nous avons divisé l'année en trois saisons; hiver, de novembre à février, été, de mai à août, et mois équinoxiaux.

I.—VARIATION SÉCULAIRE.

Notre série, faute d'homogénéité, est tout-à-fait impropre à rechercher la variation séculaire. Il semblerait qu'il y a plus de pulsations les années magnétiquement calmes, mais ceci est fort incertain.

II.—Variation annuelle.

Les deux premières séries semblent mettre un minimum en février ou mars et un maximum en été, mais la troisième indiquerait le contraire. En réalité notre série ne manifeste pas de marche annuelle, maximum et minimum se présentant à peu près à tous les mois et sans ordre. Ceci ne veut pas dire du reste qu'une série plus homogène ou mieux étudiée ne montrerait pas une variation annuelle.

III.—Variation diurne.

Dans l'ensemble elle est fort nette. Le Bulletin de notre observatoire la donnera pour chaque année et pour chaque série. Voici l'ensemble. Les pulsations ont été réduites à 1000 par an et adoucies par la méthode d'une double moyenne. Pour calculer l'ensemble on a donné un poids égal à chaque série et non à chaque année. 0^h représente l'intervalle de 0^h à 1^h, c'est-à-dire minuit et demie et ainsi des autres heures.

Tableau 1.

Heure	Pulsations	Heure	Pulsations	Heure	Pulsations	Heure	Pulsations
h		h		h		h	
0	**88.9**	6	22.0	12	29.6	18	36.6
1	78.5	7	*21.2*	13	28.0	19	50.0
2	58.2	8	22.3	14	26.4	20	60.1
3	42.6	9	25.2	15	24.3	21	67.3
4	32.2	10	29.5	16	*18.8*	22	75.1
5	25.4	11	**31.4**	17	21.6	23	84.9

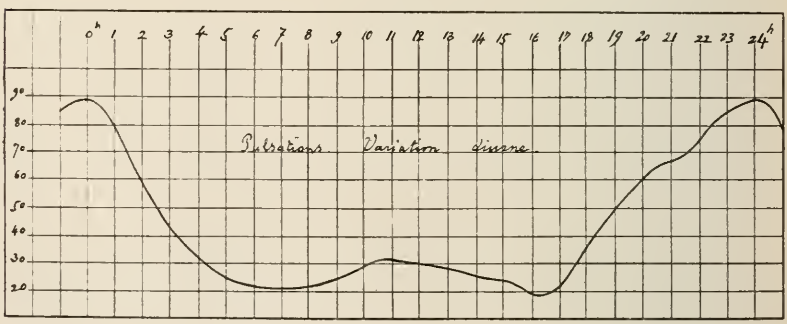

Fig. 1

Remarque 1.—*Années Calmes et Années Actives.*

Si nous n'avons pas trouvé d'influence marquée de l'activité solaire sur le nombre des pulsations, il n'en est pas de même, si nous ne nous trompons, quand il est question de la marche diurne. Très nette les années magnétiquement calmes, elle l'est fort peu les années actives, même si le nombre des cas est considérable. C'est ainsi que l'année 1916, qui a le nombre énorme de 2000 séries de pulsations, manifeste tout-à-fait médiocrement leur allure diurne. Pour mieux mettre en relief la différence de ces deux types, prenons 5 années calmes, 1910 à 1914, et 5 années actives, 1904 à 1908, sans adoucir ni réduire les moyennes.

Tableau 2

Heure	Années Calmes	Années Actives	Heure	Années Calmes	Années Actives
h			h		
0	**50.2**	1.6	12	15.0	1.8
1	41.2	2.6	13	14.6	1.0
2	38.0	1.4	14	11.8	0.8
3	29.2	1.4	15	14.0	1.4
4	26.2	0.8	16	9.2	0.6
5	18.2	0.6	17	*7.6*	*0.2*
6	14.8	*0.4*	18	21.6	2.0
7	11.0	0.8	19	23.4	2.4
8	*9.8*	2.0	20	33.8	3.2
9	10.8	1.2	21	29.8	2.2
10	17.4	**2.6**	22	35.4	3.2
11	**17.8**	1.8	23	41.6	**4.0**

Tableau 3.—*Coefficients Harmoniques.*

Années	R_1	α_1	R_2	α_2	R_3	α_3	R_4	α_4
		°		°		°		°
Calmes	14.4	94	7.4	99	1.6	326	1.4	59
Actives	0.6	125	0.9	146	0.3	322	0.3	289

L'origine du temps est la première heure ou, d'après ce qui précède, minuit et demie.

Ces cinq années actives ayant été fort pauvres, nous faisons dessiner en regard l'année 1916, assez active, et très riche en pulsations. On verra combien mal elle donne l'allure diurne. Disons ici que le faible nombre d'années étudiées ne permet sans doute

pas de considérer comme bien démontrée l'existence de plusieurs types de variation diurne. Peut-être cependant le fait mérite-t-il considération.

Fig. 2

Remarque 2.—*Variation Saisonnière.*

Nous n'avons traité à part les saisons qu'en 1896-99 et depuis 1908. Cela nous fait en somme trois séries de durée presque égale ayant chacune sa sensibilité propre. On trouvera dans le Bulletin chacune de ces séries; contentons nous ici des ensembles.

TABLEAU 4.

Heure	Hiver	Équinoxes	Été	Heure	Hiver	Équinoxes	Été
h				h			
0	**10.1**	**9.4**	8.6	12	1.6	2.7	3.9
1	8.4	9.0	**9.7**	13	1.9	2.6	**4.0**
2	5.2	6.4	7.4	14	**2.1**	2.5	2.9
3	3.3	3.9	4.2	15	1.7	**2.9**	2.0
4	2.9	2.6	3.0	16	*1.2*	2.2	*1.5*
5	2.5	1.9	2.2	17	1.9	*2.2*	1.9
6	1.6	1.6	*1.9*	18	4.1	4.0	3.2
7	*1.0*	*1.5*	2.1	19	6.5	5.5	4.5
8	1.0	1.6	2.0	20	8.5	6.8	5.1
9	1.4	2.1	2.4	21	9.9	7.5	6.1
10	1.8	2.4	3.2	22	9.9	7.8	7.2
11	1.6	2.5	3.6	23	9.9	8.5	7.5

Ces nombres sont adoucis et réduits à 1000.

TABLEAU 5.—*Coefficients Harmoniques.*

Saison	R_1	α_1	R_2	α_2	R_3	α_3	R_4	α_4
		°		°		°		°
Hiver	4.2	114	2.0	134	0.7	198	0.3	33
Équinoxes	3.2	112	2.7	113	0.2	68	0.4	22
Été	2.4	100	2.1	101	0.3	13	0.7	34

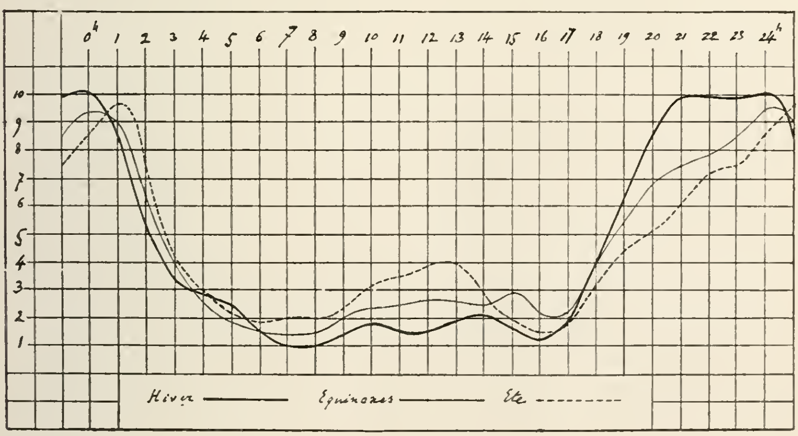

FIG. 3

Les coefficients R_1, α_1, α_2 suivent un ordre bien marqué. En suite de là, comme le fait voir le graphique, le maximum du milieu du jour est plus important et mieux dessiné en été. Vient ensuite la saison des équinoxes et enfin l'hiver. Ceci est à rapprocher de ce que nous venons de voir, que ce maximum est plus marqué aux années magnétiquement calmes.

Remarque 3.—*Pulsations Plus ou Moins Rapides.*

Les pulsations des trois groupes que nous distinguons ont été étudiées pour la deuxième et la troisième séries. Nous ne donnons ici que les ensembles.

Tableau 6.

Heure	Rapides	Moyennes	Lentes	Heure	Rapides	Moyennes	Lentes
h				h			
0	74	84	83	12	47	32	31
1	46	75	75	13	41	28	30
2	38	59	59	14	31	28	29
3	41	48	45	15	38	28	26
4	30	38	37	16	36	22	20
5	25	29	27	17	26	26	25
6	32	26	21	18	31	42	41
7	47	22	20	19	36	52	54
8	51	20	19	20	39	56	63
9	31	24	23	21	52	59	67
10	20	29	30	22	71	66	68
11	32	33	33	23	85	77	76

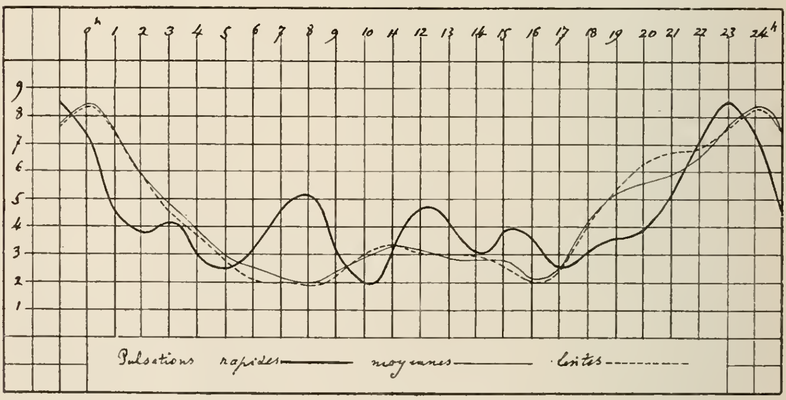

Fig. 4

Manifestement les pulsations que nous avons appelées lentes et moyennes ont absolument la même marche diurne. Il est même surprenant que, tracés pour un très petit nombre d'années, les graphiques se ressemblent de si près. Nos pulsations rapides auraient une allure assez différente. On peut seulement soupçonner que le nombre des cas est trop limité et la variation insuffisamment bien déterminée. Ceci nous amène à ajouter un mot sur les *spasmes*.

REMARQUE 4.—*Spasmes*.

M. le Dr. van Bemmelen montre que les spasmes sont des pulsations rapides qu'un enregistrement trop lent ne permet pas de séparer. Depuis que notre bifilaire est muni d'un double miroir (1913), il arrive souvent que les deux miroirs enregistrent ensemble le même phénomène, chaque image étant à première vue bien satisfaisante. Alors il n'est pas rare qu'un des miroirs montre des pulsations rapides, faciles à voir et à compter, tandis que sur l'autre trace on a seulement un épaississement du trait qu'on qualifierait de spasme sans le témoignage de l'autre miroir: on a ainsi pris sur le fait la vérité de ce qu'affirme M. van Bemmelen. Il semble pourtant que, si quelques spasmes sont des pulsations, on n'a pas prouvé que cela soit vrai de tous.

Or examinons de près un spasme bien caracterisé; nous aurons probablement l'impression que l'épaississement du trait est plus fort au milieu qu'au début et à la fin. Si nous avons donc sous les yeux des oscillations dont les images se confondent, ces oscillations n'ont pas une amplitude constante, c'est-à-dire ne sont pas des pulsations.

M. van Bemmelen fait une remarque qui confirme ce que nous soupçonnons. Ayant rangé les pulsations selon leur rapidité, il observe que les coefficients harmoniques se trouvent former une gradation croissante, sauf seulement ceux des spasmes qui refusent de se mettre à leur rang parmi les pulsations rapides. Cela se comprend aisément si les spasmes ne sont pas tous des pulsations. On conçoit aussi que la marche diurne de phénomènes qui ne sont pas identiques soit différente. Pour établir l'inégalité diurne des spasmes, nous avons pris les années de 1911 à 1916. Les cas ont été réduits à 100 par an, puis on a adouci les moyennes. Voici le résultat.

TABLEAU 7.

Heure	Spasmes	Heure	Spasmes	Heure	Spasmes	Heure	Spasmes
h		h		h		h	
0	**11.1**	6	5.4	12	1.7	18	0.7
1	9.8	7	4.5	13	1.4	19	1.3
2	7.3	8	3.9	14	1.1	20	2.4
3	6.5	9	3.4	15	0.8	21	4.8
4	5.9	10	2.6	16	0.7	22	7.6
5	5.6	11	2.0	17	*0.5*	23	9.7

TABLEAU 8.—*Coefficients Harmoniques.*

R_1	a_1	R_2	a_2	R_3	a_3	R_4	a_4
	°		°		°		°
2.1	25	1.7	97	1.8	109	0.6	116

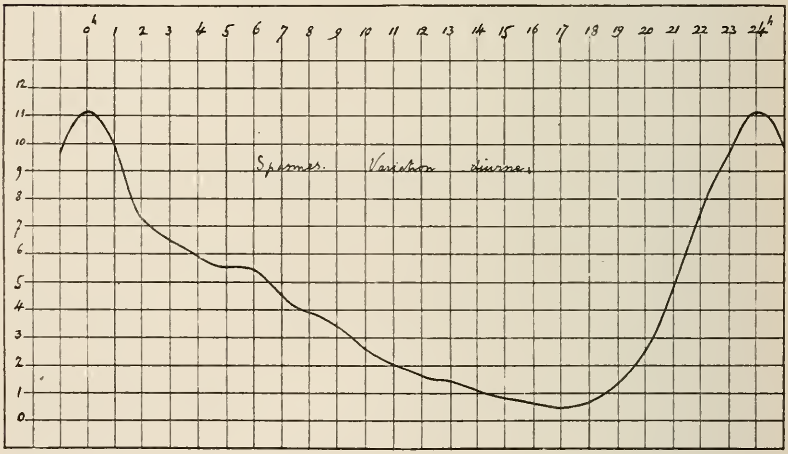

FIG. 5

Cette inégalité à un seul maximum diffère notablement de ce que nous avons obtenu pour les pulsations et en particulier pour les pulsations rapides. Il ne faut pas être trop affirmatif pour des conclusions qui ne reposent que sur un nombre si limité de cas, mais peut-être oserons-nous dire que ce que nous venons de suggérer n'est pas sans probabilité.

Lu-kia-pang, 1 avril 1917.

ON THE INFLUENCE OF LUNAR DECLINATION ON THE LUNAR-DIURNAL VARIATION OF MAGNETIC DECLINATION AT ZIKAWEI.

By S. Chapman.

Having read with much interest Father J. de Moidrey's investigation of the influence of lunar declination on the lunar-diurnal variation of magnetic declination at Zikawei,[1] and desiring to see how far theory could account for his results, I decided to calculate the Fourier coefficients of the first two harmonic components of the variations: (*a*) for the whole saros 1890-1908; (*b*) for the days when the Moon was at or near its nodes; and (*c*, *d*) for the epochs of maximum north and south declination, respectively. The results are given in Table 1.

Table 1.—*Formula:* $C_1 \sin (t + \theta_1) + C_2 \sin (2t + \theta_2)$.
(t denotes local lunar time measured from upper transit, at the rate of 15° per hour.)

	West Declination				Horizontal Intensity				Vertical Intensity			
	C_1	θ_1	C_2	θ_2	C_1	θ_1	C_2	θ_2	C_1	θ_1	C_2	θ_2
	′	°	′	°	γ	°	γ	°	γ	°	γ	°
Saros	0.031	−1	0.248	87	0.41	249	1.20	118	0.45	78	0.99	282
Nodes	0.054	73	0.274	91	0.73	236	1.49	114	0.35	112	1.39	275
North	0.161	37	0.292	95	0.49	347	1.66	112	0.54	75	1.19	290
South	0.192	292	0.206	101	0.52	249	0.58	124	0.32	113	0.93	303

As regards order of magnitude, the results for the saros may be compared with similar data obtained, from other periods of years and by other methods of computation, by Dr. van Bemmelen[2] and the present writer.[3] Dr. van Bemmelen dealt with the period 1890-1900, while my own data refer to the years 1897-1903. The three sets of figures are given in Table 2, which refers to the annual mean lunar-diurnal variation of the various elements over terms of several years.

[1] *Cf. Terrestrial Magnetism*, vol. 22, March, 1917, p. 44; note that p. 46 is out of place, and should be read in between pp. 43, 44. Father de Moidrey kindly communicated his results to me in manuscript before publication.

[2] *Meteorologische Zeitschrift*, May, 1912, p. 220.

[3] The latter are not yet published in detail, but have been communicated to the Royal Society as part of a general discussion of the diurnal-magnetic variations.

TABLE 2.

Author	West Declination				Horizontal Intensity				Vertical Intensity			
	C_1	θ_1	C_2	θ_2	C_1	θ_1	C_2	θ_2	C_1	θ_1	C_2	θ_2
	′	°	′	°	γ	°	γ	°	γ	°	γ	°
de Moidrey (1890-1908)	0.031	−1	0.248	87	0.41	249	1.20	118	0.45	78	0.99	282
van Bemmelen (1890-1900)	0.025	107	0.132	119	0.20	41	0.59	104	0.11	10	1.00	275
Chapman (1897-1903)	.....	...	0.142	93	....	...	0.48	118	....	...	1.05	253

The 24-hour component in Table 2 is not the true 24-hour term, which mainly consists of a variation of constantly changing phase, vanishing in the mean of a lunar month unless this phase-change is taken into account. In my own calculations this has been done, so that the result represents something quite different from the above 24-hour terms, which are probably chiefly accidental.

The phases of the semi-diurnal terms agree fairly well for all three elements, considering their small amplitudes and the difference between the underlying data. In the case of the vertical intensity, the three amplitudes C_2 are in excellent agreement: the values of C_2 which I have derived from Father de Moidrey's results for the other two magnetic elements are, however, about twice as great as Dr. van Bemmelen's and my own values, which agree fairly well with one another. This difference is rather surprising, and, if no numerical slip is responsible for it, deserves closer examination.

As regards the effect of changes in the declination of the Moon, the theory of the lunar-diurnal magnetic variation which I have discussed in several recent papers (*Phil. Trans.* A, 213, 214, 215) would suggest the following conclusions. The lunar semi-diurnal atmospheric tide, which is probably the primary factor in the magnetic variations, would be expected to vary in amplitude proportionately to $\cos^2\delta$, where δ is the declination of the Moon. There is no satisfactory observational evidence on this point at present, though I am now taking steps to obtain the necessary data; if the theoretical expectation is confirmed, we ought to find corresponding changes in the amplitude C_2 of the lunar semi-diurnal *magnetic* variation. The amplitude should be greatest when the Moon is near the nodes, and least at extreme

north and south declinations. The monthly mean amplitude should, of course, lie between these extremes.

The extreme declination of the Moon varies throughout the saros period from about 18° to about 29°. Taking $\cos^2 25°$, i. e., 0.82, as the value of the mean square of $\cos \delta$ at extreme declinations, we should expect the values of C_2 at north and south maximum declinations to be about 18 per cent less than at the nodes. Table 1 affords the following observed ratios:

	Declination	Horizontal Intensity	Vertical Intensity
North ÷ Node	1.06	1.11	0.86
South ÷ Node	0.75	0.39	0.67
Mean	0.91	0.75	0.76
	Mean of all, 0.81.		

The final mean agrees closely with the theoretical value, but the agreement is to some extent accidental, as appears from the individual values of the ratios. The discordances from the mean are, however, not greater than might be expected in view of the small amount of material on which the values of the last three lines of Table 1 are based.

The mean value of $\cos^2\delta$ over a long period of whole months will be approximately 0.93, and this should theoretically be the value of the ratio of C_2 derived from the saros as a whole to that derived from the days of no lunar declination. Comparing the values of C_2 in the first two lines of Table 1, we find the following observed values:

Declination, 0.91; *Horizontal Intensity*, 0.81; *Vertical Intensity*, 0.71; *Mean*, 0.81.

The mean value is, it appears, still smaller than 0.93, but for the reasons already mentioned the observed value is somewhat uncertain. The evidence seems, on the whole, favourable to the conclusion suggested by the theory, but much more would be necessary to substantiate the conclusion.

The tidal theory does not suggest any difference between the values of C_2 or θ_2 corresponding to limiting northern and southern declinations. The observed data perhaps indicate that differences do, in fact, exist, but this may only be the result of accidental errors.

Besides the semi-diurnal tides, there should be a lunar-atmospheric tide of period 24 hours and amplitude proportional to $\sin \delta$, and, therefore, of opposite sign at the two limiting declinations. The magnetic effect of such an atmospheric oscillation would be expected to consist of a diurnal component of opposite signs during the semi-lunations of northern and southern declination, but of constant phase; and also components of other periods, of reversed signs during the two halves of the month, and also of varying phase. All these terms would vanish in the mean of a lunation (apart from the influence of the Moon's varying dis-

tance), but the evanescence of this 24-hour term is for a different reason, of course, from that of the 24-hour term of gradually varying phase previously mentioned.

These 24-hour components should be absent from the first two lines of Table 1, but present, with phases differing by 180°, in the last two lines. In the case of the West-Declination column there is perhaps some indication of this, but in all cases the accidental errors in C_1 seem so large as to render the question very uncertain, so far as observation goes. It is to be hoped, however, that these brief notes will induce magneticians to investigate more closely the influence of the Moon's declination on the magnetic variations, and so elucidate the points here suggested on the basis of the tidal theory.

Royal Observatory,
Greenwich, *May 17, 1917.*

LETTERS TO EDITOR

ON THE MAGNETIC STORM OF AUGUST 8–9, 1917.

A magnetic storm of large magnitude and very rapid changes in the magnetic elements began abruptly at the magnetic observatory, at Cheltenham, Maryland, at 23^h 12^m, 75th meridian time, Aug. 8, and ended at about 24^h, Aug. 9, 1917. The storm occurred in two phases, the first phase ending at 6^h Aug. 9, and the second phase beginning at 16^h, Aug. 9. During the interval between these phases, there were rapid oscillations of double amplitude averaging 6′ in D (declination), 40γ in H (horizontal intensity) and 6γ in Z (vertical intensity). The beginning of the first phase was indicated by a slight increase (westerly) of D, then a sudden decrease of 8′.6; by a sudden increase of 106γ in H; and by an increase of 5γ in Z, followed by an abrupt decrease of 18γ. Immediately after, the storm was in full swing.

The first phase was characterized by an increase in the average value of D and by a large decrease in H and in Z. During the second phase, the average value of D was about normal, while H and Z increased enormously. The period of the largest and most rapid disturbances extended from 16^h to 21^h. The extremes of the disturbance are given in the following table:

Phase	West Decl.		Hor. Intensity		Vert. Intensity	
	Time	Value	Time	Value	Time	Value
	h m	° ′	h m	γ	h m	γ
Beginning	....	6 11	....	19300	....	55540
Maximum, 1st phase	1 28	7 03	23 12	19467	23 12	55545
Minimum, " "	5 07	5 36	3 30	18833	....	55200[1]
Range, " "	....	1 27	....	634	....	345[1]
Maximum, 2nd phase	17 47	6 29	17 39	19571[2]	19 12	56359
Minimum, " "	22 18	5 38	22 43	19159	21 34	55512
Range, " "	....	0 51	....	412[2]	....	847

[1] The Z-spot was beyond the limits of the magnetogram from 1^h 08^m to 2^h 04^m, from 2^h 58^m to 4^h 05^m and from 4^h 38^m to 4^h 40^m, Aug. 9; the range of Z may have been as great as that of H.

[2] The H-spot passed beyond the limits of the magnetogram at 17^h 39^m and again at 17^h 49^m, Aug. 9; the range was therefore greater than 412γ.

George Hartnell, *Magnetic Observer.*

U. S. Coast and Geodetic Survey.

NOTE CONCERNING THE MEASUREMENT OF IONIC DENSITY ON THE TOP OF A TOWER.

On pages 35–37 of the March issue of the Journal for the current year, P. L. Mercanton gives some very interesting results of measurements of the atmospheric ionization made by him on a parapet near the top of a tower, and in the interior of the tower at its base. He finds that if n_+ and n_- refer, respectively, to the positive and negative ionic-densities, n_+/n_- is much larger for the measurement made in the strong electric field near the top of the tower than in the zero electric field in the interior of its base. Thus, for n_+/n_- as measured at the top of the tower, values 4.33, 2.16, 4.46, and 1.70 were obtained on four different occasions, while the corresponding values for the foot of the tower were, respectively, 1.31, 1.09, 1.24, and 1.19.

I wish to call attention to the confirmation, afforded by these observations, of the view put forward in my former communication,[1] as to the effect of the charge induced on the Ebert ion-counter by the potential-gradient in modifying the values obtained in ionic-density measurements. The theory of the phenomenon shows that, for a potential-gradient of the normal sign, measurements of n_+ should be unaffected by the induced charge, while those of n_- should be too small. The effect of the negative induced charge on the instrument is to retard the velocity of the approaching negative ions. Thus, these ions move slower than the incoming stream of air, with a result that a smaller number of them enter the instrument per second than would enter if there were no induced charge. The positive ions are accelerated by the induced charge, but theory shows that the *excess* number of ions entering the instrument is just equal to the number which are captured by the outer cylinder of the apparatus, so that the measurements of n_+ are unaffected by the induced charge.

The above conclusions are consequently in complete harmony with P. L. Mercanton's results, since they predict small values of n_- and, consequently, large values of n_+/n_- for places where the potential-gradient is high, as for example, on the top of a tower.

I may here take the opportunity of referring to some data recently published by A. Gockel, concerning the effect of a tower on the ionic density in its vicinity.[2] In the paper,[1] already cited, I have considered the problem of the tower, and find that, as regards the *true negative ionic-density* (n_-), the space around the tower may, in general, be divided into two regions: a region represented by the dotted portion of Fig. 1, in which there are no negative ions, and a region external to this, in which the ionic density is normal. For low potential-gradients,

[1] *Terr. Mag.*, vol. 19, pp. 205–209, 1914.

[2] Luftelectrische Beobachtungen im schweizerischen Mittelland, im Jura und in den Alpen. *Neue Denkschriften der Schweizerischen Naturforschenden Gesellschaft*, vol. 54, No. 1, pp. 34-35, 1917. See also pp. 135-138 of the present number of the Journal.

or strong wind velocities, the dotted region would be evanescent, or practically so. In any case, however, for a point outside the dotted region, n_- should be normal. Theory also shows that n_+ has its normal value at all points of the space around the tower.

Gockel, using, presumably, an Ebert ion-counter of Günther and Tegetmeyer's pattern, has made two sets of measurements. One set was made on the top of a tower 13 meters high, and the other on a platform shielded from the potential-gradient, and situated 2 meters below the top of the tower. For the measurements in the region exposed to the field Gockel finds $n_+/n_-=2.03$, while for the shielded region, $n_+/n_-=0.92$; he considers these measurements inconsistent with the above-cited view as to the action of the tower. It must be remarked, however, that we must here carefully distinguish between two distinct phenomena. As already stated, theory shows that n_+ and n_- have their proper values in the space around the tower, for points outside the critical region represented by dotted portion in Fig. 1; but when we introduce an *instrument* to measure the ionic densities, the error caused by the induced charge on the instrument produces its effect just as it does when measurements are made over the surface of the ground. It would thus appear that the difference between the values of n_+/n_- for the shielded and the unshielded positions is attributable to the induced charge on the instrument in the latter case, and there is no evidence to show that it is due to the tower directly. In order to reduce the instrumental error it is necessary to shield the instrument with wire netting, as discussed on pages 210-212 of my paper,[1] and on page 215 in relation to the tower.

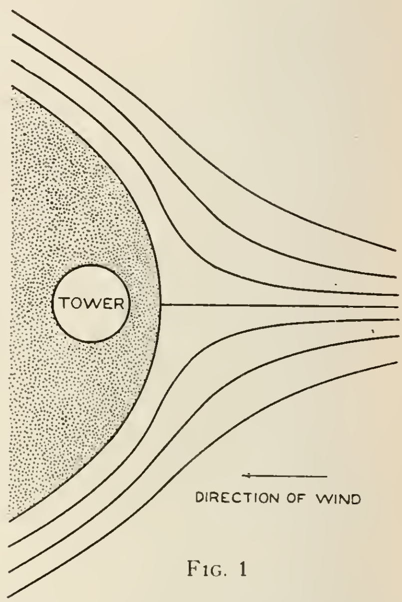

FIG. 1

It seems, therefore, that Gockel's results are in no way inconsistent with my theory of the action of the tower, but that, together with those of P. L. Mercanton, they form a very valuable confirmation of the views put forward in my paper[1] as to the effect of the induced charge on the instrument.[3]

It may be worth while to add that any possible advantage accruing from the making of atmospheric-electric observations on the top of a

[3] For further observations concerning the order of magnitude of the effect of the induced charge in the case of the instrument of Günther and Tegetmeyer's design, see a paper by E. H. NICHOLS, *Terr. Mag.*, vol. 21, pp. 87-99, 1916, together with a reply by the present writer on pp. 99-102 of the same issue.

tower lies in the fact that, as shown in a former communication,[4] the potential-gradient tends to cause a real difference between the ionic densities of the positive and negative ions near the surface of the Earth, so that the densities as measured here are not entirely determined by the rates of production and recombination of ions. This effect of the potential-gradient diminishes very rapidly with the altitude, so that even at altitudes as low as 20 meters, the ionic densities should be less dependent upon variations in the potential-gradient than is the case at the ground level, except in so far as the advantage of the elevation is minimized by convectional motion of the air.

W. F. G. SWANN.

Department of Terrestrial Magnetism, Carnegie Institution of Washington.

VALUES OF THE MAGNETIC ELEMENTS AT THE SAMOA OBSERVATORY.

TABLE 1.—*Mean Annual Values, 1905–1916.*

Year (Middle)	East Declination *D*	South Inclination *I*	Intensity Horizontal *H*	Intensity Vertical *Z*	Remarks
	° ′	° ′	γ	γ	
1905	9 37.0	—29 11.8	35675	—19935	Final Values
1906	38.5	15.7	655	19977	
1907	40.1	18.9	637	20010	
1908	41.9	21.8	613	036	
1909	43.9	....	590	....	Preliminary Values
1910	45.7	....	550	....	
1911	47.4	36.1	527	183	
1912	50.3	41.2	487	230	
1913	51.9	45.9	455	277	
1914	53.7	49.5	429	313	
1915	56.8	52.7	389	332	
1916	59.9	54.5	364	343	

Remarks for Table 1.

The values for the years 1909–1916 are preliminary ones; they may require slight corrections of a few tenths of a minute for declination and inclination, and a few gammas for the intensity components. The final values of *I* and *Z* for 1909 and 1910 must be deferred.

The tabular quantities are based upon "Stationstheodolit Tesdorpf 2025" and "Stationsinductor Schulze 2." The values have not yet been referred to the International Magnetic Standards (I. M. S.), as determined from the extensive comparisons of the Department of Terrestrial Magnetism; the relations which may serve for the reductions to I. M. S. are given on next page.

[4] *Terr. Mag.*, vol., 18, p. 163, 1913. See also, E. VON SCHWEIDLER, *Wien. Ber.*, vol. 117, p. 653, 1908.

TABLE 2.—*Preliminary Monthly Mean Values, 1914–1916.*

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Mean
	East Declination: 9°+												
	′	′	′	′	′	′	′	′	′	′	′	′	′
1914	53.5	54.1	53.0	53.2	53.0	53.0	53.7	53.7	53.7	53.7	54.4	56.0	53.7
1915	55.4	55.8	56.0	56.3	56.6	56.6	56.9	57.5	57.4	57.5	57.7	58.2	56.8
1916	58.6	59.1	58.3	58.9	59.1	59.5	59.9	60.2	60.6	61.1	61.5	61.5	59.9
	Horizontal Intensity: 35000 γ +												
	γ	γ	γ	γ	γ	γ	γ	γ	γ	γ	γ	γ	γ
1914	446	449	447	426	420	429	422	415	415	422	422	431	429
1915	421	409	397	402	398	357	376	383	385	373	375	389	389
1916	397	393	375	361	359	364	354	337	358	354	362	356	364
	Vertical Intensity: — 20000 γ —												
	γ	γ	γ	γ	γ	γ	γ	γ	γ	γ	γ	γ	γ
1914	295	—	295	297	296	—	310	321	332	330	332	323	313
1915	323	320	330	334	336	335	331	327	329	341	341	331	332
1916	331	328	328	330	332	333	355	356	360	360	352	357	343

Remarks for Table 2.

The values as given may require slight corrections, which, however, it is believed will not exceed a few tenths of a minute for the declination, and a few gammas for the intensity components. The values have not yet been reduced to International Magnetic Standards (I. M. S.); the following relations apply:

Declination:	I. M. S. = Samoa $-3'.6$
Inclination:	I. M. S. = Samoa $+1'.3$.
Horizontal Intensity:	I. M. S. = Samoa $+0.0004H$.
Vertical Intensity:	I. M. S. = Samoa $-0.0005Z$.

East declination is regarded as plus, and south inclination, or south vertical-intensity, as minus.

Apia, Samoa, June 24, 1917.

G. ANGENHEISTER.

OCEAN MAGNETIC OBSERVATIONS, 1905-1916, AND REPORTS ON SPECIAL RESEARCHES,[1] BY L. A. BAUER, W. J. PETERS, J. A. FLEMING, J. P. AULT, AND W. F. G. SWANN.

[*Authors' Abstract.*]

This publication is the third of the series by the Department of Terrestrial Magnetism of the Carnegie Institution of Washington, bearing the general title "Researches of the Department of Terrestrial Magnetism." The present volume, entitled "Ocean Magnetic Observations, 1905–1916, and Reports on Special Researches," contains the final results of the ocean magnetic observations made aboard the *Galilee* in the Pacific Ocean, 1905–1908, and aboard the *Carnegie* in the Atlantic, Indian, and Pacific Oceans, 1909–1914, together with preliminary results of the observations on the 1915–1916 portion of the *Carnegie's* fourth cruise. The special reports relate to auxiliary observations made aboard these vessels, or to special investigations. The first and second volumes, besides some special reports, contained the methods and results of the land magnetic observations 1905–1910, and 1911–1913. The fourth volume is to contain the final results of the magnetic-survey work, on land and at sea, 1914–1917. It is then hoped to be able to issue a summary volume (probably No. V) which will contain the results of all magnetic observations of the Department of Terrestrial Magnetism, referred to a common epoch; the construction of new world magnetic charts may then be successfully undertaken as well as a new analysis of the Earth's magnetic field with its attendant "greater problems."

The *preliminary results of the ocean magnetic observations* apply to the cruise of the *Carnegie* from Brooklyn, March 1915, to San Francisco, September 21, 1916. The similar results from the continuation of the cruise from San Francisco to Easter Island and around the Horn to Buenos Aires, November 1916 to March 1917, will be found on pp. 139-144 of the present issue of this Journal. Hence the results of the ocean magnetic work of the Department of Terrestrial Magnetism from 1905 to 1917 (March) are now in print.

Table 1, which appears as No. 72 on page 358 of the volume under review, *shows for each cruise of the Galilee and of the Carnegie the*

[1] Researches of the Department of Terrestrial Magnetism (vol. III): Ocean magnetic observations, 1905–1916, and reports on special researches. L. A. Bauer, W. J. Peters, J. A. Fleming, J. P. Ault, and W. F. G. Swann. Quarto. Carnegie Institution of Washington Publication No. 175 (vol. III). 1916. VIII + 448 pp., frontispiece and 25 pls., and 35 text-figures.

Also issued separately as follows: The magnetic work of the *Galilee*, 1905–1908; the magnetic work of the *Carnegie*, 1909–1916, and some discussions of the ocean magnetic work, 1905–1916; results of atmospheric-electric observations made aboard the *Galilee* (1907–1908), and the the *Carnegie* (1909–1916).

number of days at sea[2], *the length of the cruise in nautical miles, and the number of observed values of the magnetic declination, inclination, and intensity of the Earth's magnetic field.* The subsequent columns give the average time-intervals, as well as the average distances apart, between the observations. The entries in the bottom row of the table summarize the work of the two vessels from August 1905 to September 1916.

Table 1.—*Summary of the Ocean Magnetic Work of the Galilee and the Carnegie, 1905–1916 (September).*

Vessel and Cruise	Number		No. of obs'd values			Average time interval			Average distance apart		
	Days	Miles	Decl'n	Incl'n	Hor. Int.	De-cl'n	In-cl'n	Hor. Int.	De-cl'n	In-cl'n	Hor. Int.
						days	*days*	*days*	*mil's*	*mil's*	*mil's*
Galilee, Cruise I, 1905	92	10,571	74	58	59	1.2	1.6	1.6	143	182	179
Galilee, Cruise II, 1906	168	16,286	95	88	91	1.8	1.9	1.8	171	185	179
Galilee, Cr. III, 1906-08	334	36,977	155	169	171	2.1	2.0	2.0	237	219	216
Totals for *Galilee*	594	63,834	325	315	321	1.8	1.9	1.9	196	203	199
Carnegie, Cr. I, 1909-10	96	9,600	98	68	69	1.0	1.4	1.4	98	141	139
Carnegie, Cr. II, 1910-13	798	92,829	858	648	643	0.9	1.2	1.2	108	143	144
Carnegie, Cr. III, 1914	84	9,55[illegible]	108	81	80	0.8	1.0	1.0	89	118	119
Carnegie, Cr. IV, 1915-16	375	48,626	665	369	368	0.6	1.0	1.0	73	132	132
Totals for *Carnegie*	1,353	160,615	1,729	1,166	1,160	0.8	1.2	1.2	93	138	138
Totals, *Galilee* and *Carnegie*	1,947	224,449	2,054	1,481	1,481	0.9	1.3	1.3	109	152	152

It will be seen that the aggregate length of all the cruises of the *Galilee* and *Carnegie* through September 1916, is 224,449 nautical miles. The average time-intervals and average distances apart for the *Galilee* work have been decreased by about 45 per cent in the *Carnegie* work. The increased efficiency, or productiveness, has resulted from the fact that the *Carnegie* is a non-magnetic vessel and because of the steady improvement in the instrumental appliances and observational methods.

After a general introduction and a brief account of previous ocean magnetic surveys, the magnetic work of each vessel is treated separately. The *headings of the main chapters or sections for the Galilee work are:* General remarks and description of the *Galilee;* synopses of the *Galilee's* cruises, 1905–1908; methods of work on the *Galilee;* magnetic instruments and list of instruments used in the *Galilee* work; specimens of observations and of computations (during swing of vessel and on course); shore magnetic work; determination of geographic position at sea; reduction formulæ and determination of constants; ship constants and deviation coefficients; specimen computations of deviation-corrections; ocean magnetic observations on the *Galilee* and tables of results, 1905 to 1908; shore magnetic observations for the *Galilee* work, 1905 to 1908; extracts from Director's instructions for cruises and observational work; extracts from commander's field reports and abstracts of the

[2] In the case of the *Galilee* work, to the number of days at sea were added the days spent in the harbor-swings.

Galilee's log; discussion of alidade corrections for standard compass; and auxiliary observations.

The *section headings for the Carnegie work* are in general the same, except that, since the *Carnegie* is a non-magnetic vessel, the sections dealing with the determination and discussion of deviation corrections are omitted. The construction of the *Carnegie* in 1909 is described and illustrated. The synopses of cruises are for the period 1909–1916 (September).

A *special feature of the Carnegie work* is the full account of the new instruments devised by various members of the Department of Terrestrial Magnetism, and constructed in the Department's instrument-shop. Thus there are descriptions and illustrations of the marine collimating-compass for magnetic declination, the sea deflector for horizontal intensity and declination, the sea dip-circle for inclination and total intensity, the marine earth-inductor for inclination, and a reversible gimbal stand. The descriptions also give the scheme or method of observation with each instrument.

The section on *geographic position at sea* is given special treatment under the *Carnegie* work, and specimens of observations and computations are added.

Under extracts from the *commander's field reports* are found, among other matters, notes on the occurrence of thunder at sea as observed on the *Carnegie's* cruise, 1915–1916, and an account of the Carnegie's sub-Antarctic voyage, 1915–1916.

Atmospheric-Electric Observations.

The first special report by L. A. Bauer and W. F. G. Swann deals with the results of the atmospheric-electric work on board the *Galilee*, 1907–1908, and on the *Carnegie*, 1909–1916 (April). From the beginning of the ocean work of the Department of Terrestrial Magnetism, it has been its aim to include in the program of scientific work whatever additional observational researches could be carried on advantageously and profitably without conflicting with the prime object assigned to the Department: the general magnetic survey of the globe. The problem which naturally suggests itself as closely related to that of terrestrial magnetism is that of terrestrial electricity, which embraces the following subjects: (*a*) the electric currents circulating within the Earth's crust; (*b*) the Earth's electric charge, and (*c*) the conducting properties of the atmosphere. Subject *a* at present is one of the combined laboratory and observatory investigation. Subjects *b* and *c* together form the science termed "atmospheric electricity." It is only with regard to field observations and results in the latter that the present report concerns itself.

The need in atmospheric electricity of a general series of accurate observations over as large a portion of the Earth's surface, as possible, may perhaps have been first definitely set forth by the late Professor Rowland in his address before the Congress of Electricians, held at

Paris, September 1881. Later, Professors J. Elster and H. Geitel, in their letter to the Carnegie Institution of Washington, dated Wolfenbüttel, Germany, January 26, 1902, recommended that it would be in full harmony with the proposed plan to combine with the organization of international magnetic work also the inauguration of observations pertaining to the electric condition of the Earth and of the atmosphere.

A general electric survey of the oceanic areas possesses peculiar advantages over that of land areas, not merely because of the greatly preponderating extent of area, but because of the freedom from the disturbing influences of topographic and cultural features. To reap the full benefit of this latter advantage, however, it is essential to eliminate as far as possible the disturbing influences caused by the vessel itself, on which the observations are made. In brief, the difficulties to be overcome, are both of an instrumental nature and of an observational nature.

During a special trip to Europe in the spring of 1905, the Director of the Department received most valuable aid and counsel regarding atmospheric-electric work from Professors von Bezold, Chree, Ebert, Elster and Geitel, Mascart, Schuster, Shaw, Rücker, and Wiechert.

It may be recalled that the types of instruments used in atmospheric-electric work ten years ago were the subject of frequent criticism and changes. Before an instrument had been completed by a European maker, it had been modified or superseded by some other instrument. Accordingly, it was not until the middle of the third and final cruise of the *Galilee,* namely, in August, 1907, that the ocean measurements of the electrical elements of the atmosphere could be undertaken, and then only in a preliminary manner. The work was continued tentatively on the first and second cruises of the *Carnegie,* 1909–1913.

When the laboratory of the Department of Terrestrial Magnetism at Washington was completed in 1914, the requisite facilities became available for experimental and theoretical studies of the various atmospheric-electric instruments and methods of observation. As the result, certain modifications in existing types of instruments could be made, and new types and methods devised, which have been described in various articles by Swann in this Journal. When therefore the *Carnegie* set out on her fourth cruise from New York in March 1915, the work in atmospheric electricity could be undertaken with greater hope of successful accomplishment than theretofore possible.

The main observations and results for the various cruises, as based on the observers' reports, are first set forth separately. The results for the *Carnegie's* fourth cruise are given in full; they are compiled and discussed by W. F. G. Swann. The discussion includes a comparison of the results with land values, and with former ocean values obtained by the Department of Terrestrial Magnetism and others.

The discussion of the observations led to the following general conclusions:

(1) The potential-gradient over the ocean has, according to the present observations, an average daily mean value of 113 volts per meter.

It has a distinct diurnal variation with minima about 5 a. m., and 3 p. m., and maxima about midnight and 9 a. m., the 12 hour Fourier "wave" being more prominent than the 24 hour "wave."

(2) The average values, for the whole cruise through March 1916, of conductivities and ionic contents for positive and negative ions are, $\lambda_+ = 1.44 \times 10^{-4}$, $\lambda_- = 1.19 \times 10^{-4}$ E.S.U., $n_+ = 804$, and $n_- = 677$, and the mean value of n_+/n_- is 1.22. These numbers are in close agreement with values found on land. The diurnal variation of n_+ has been investigated, and the element has been found to have a flat maximum ranging from about 6 a. m. to 2 p. m. and a minimum about midnight.

(3) The mean ocean value of the specific ionic velocities is 1.30 cm. per second per volt per cm., and is the same for ions of both signs. It is somewhat greater than the values $v_+ = 1.08$ and $v_- = 1.22$ obtained as the means for a number of land stations, but is nearer to the ionic velocities as measured for ions artificially produced in dust-free air.

(4) The mean ocean value for the air-earth current-density is 9.5×10^{-7} E.S.U.

(5) The number of pairs of ions produced per c. c. per second in a closed copper vessel over the ocean shows very little variation with season or location, and there does not appear to be any appreciable diurnal variation in the quantity. The mean absolute value of the number in question is 3.8. It is considerably smaller than the values resulting from corresponding measurements made on land, a result to be expected in view of the absence, over the ocean, of the contribution to the penetrating radiation by radioactive materials.

(6) The average radium emanation contents found over the Pacific and sub-Antarctic Oceans are respectively 3.3×10^{-12} and 0.4×10^{-12} curie per cubic meter. These values are much smaller than the mean value (88×10^{-12} curie per cubic meter) for the land. They are too small to contribute in a marked degree to the ionization over the ocean, and it is concluded that the reason for the measured ionic densities over land being, if anything, smaller than those over the ocean, is to be found in the greater purity of the ocean air as compared with the land air. The presence of dust nuclei, in fact, increases the number of ions which go into the slowly moving class, and which consequently lose their power of becoming registered in the usual measuring apparatus.

As yet no detailed analysis of the observations has been made with a view to determining the interrelations between the atmospheric-electric quantities and latitude, temperature, humidity and atmospheric pressure.

Chart-Corrections and Annual Changes.

The second special report (pp. 423–438) contains "some discussions of the ocean magnetic work, 1905–1916, by L. A. Bauer and W. J. Peters." The following general statement is made under the heading, "corrections of magnetic charts":

The *corrections in the case of the magnetic-declination charts* for the ocean routes generally traveled, have been usually below 2°, though

at times exceeding this amount. Unfortunately, the corrections are frequently of the same sign, or in the same direction, for long stretches at a time. In certain parts of the Pacific and the Atlantic Oceans the chart corrections have been about 4°, while in the Indian Ocean they reached 6°, and off the southwest coast of Australia, from 12° to 16°.

The *corrections for the charts of the lines of equal magnetic inclination* have usually been less than 5°, though amounting in certain regions to 9°.

The *corrections for the charts of the lines of equal horizontal intensity* have been of the order 0.005 to 0.015 C. G. S., and have even reached .060 C. G. S. on the most southerly cruises. In general, the corrections were found to be of the order 2 to 10 per cent.

Erroneous assumptions as to amount and sign of secular changes have been found to be partly, sometimes largely, responsible for the systematic chart-corrections.

Tables 96, 97 and 98 (pp. 432–433) give, respectively, for the Indian Ocean, the Atlantic Ocean and the Pacific Ocean preliminary average annual changes in the magnetic elements, determined from the observations at the intersections of the tracks of the *Galilee* and the *Carnegie*, 1905–1916.

Pages 434–437 contain data showing the perfection reached in the ocean magnetic work of the *Carnegie* and the absence of any deviation corrections large enough to require being considered. *Given favorable conditions of sea and weather, it would appear possible, with the instrumental appliances and methods used on the Carnegie, to make magnetic observations approaching in accuracy those made ashore on fixed supports.*

Illustrations.

A view of the *Carnegie* under sail appears as frontispiece. Plates 1–6 show views of the *Galilee,* of her instruments and of her cruises. Plates 7–19 apply to the work of the *Carnegie,* views of the vessel, of the instruments, of her work and her cruises being given. Plate 20 exhibits in colors the combined magnetic work of the Department of Terrestrial Magnetism on land and sea, 1905-1916 (October). Plate 21 is a view of the Department's laboratory and standardizing observatory at Washington. The atmospheric-electric equipment for the *Carnegie,* 1915-1916, is shown on Plate 22. Plates 23, 24, and 25 exhibit, in color, the tracks of the chief vessels on which magnetic observations were made from 1839–1916, respectively, in the Atlantic Ocean, the Pacific Ocean, and the Indian Ocean.

The 35 text-figures serve further to illustrate the various topics and instruments.

GOCKEL'S RECENT ATMOSPHERIC-ELECTRIC OBSERVATIONS IN SWITZERLAND.[1]

[*Abstract by W. F. G. Swann.*]

The general scope of this publication is illustrated by the 15 sections into which it is divided—(1) Plan of Work; (2) Measurement of ionic numbers; (3) The slowly-moving ions; (4) Dust measurements; (5) Dust-nuclei and ionization; (6) Ionic mean velocity; (7) The small ions and the conductivity; (8) Dependence of the number of small ions and the conductivity upon meteorological factors; (9) Ionization and conductivity in the mountains; (10) Ionization in the Jura and on Lake Lucerne; (11) Recombination and production of ions; (12) Penetrating radiation; (13) Effusion of ions from the ground; (14) The Earth's electric field; (15) Ionization during the fall of precipitation

Section 1 gives the *general outline of the measurements* and discussions treated in greater detail in the subsequent sections. Attention is called to the importance of a complete knowledge of the numbers and natures of the various types of ions, from an atmospheric-electric, meteorological, and even, possibly, from a phsycological standpoint. The author points out that the observations made with the Ebert ion-counter, by different observers, are by no means comparable, since the existence of ions varying over wide ranges of velocity results in the indications of the instrument depending upon the length of the cylindrical condenser and the applied potential, data which are usually not given. In Section 2 are described *experiments* on this matter. The general method consists in plotting the apparent ionic content against the potential applied to the central cylinder, and calculating the ionic velocities corresponding to the potentials at which the curve suddenly changes its slope. The results indicate that the relative importance of the different kinds of ions depends very greatly upon the place and conditions (relative humidity, amount of smoke, etc.) and the apparent ionic contents as obtained with a condenser system 40 cm. long are frequently different from those obtained with the same potential on the instrument but with a condenser tube 10 cm. long.

Section 3 is devoted to the *slowly-moving ions* discovered by Langevin, and having a specific velocity of the order of 0.0003 cm. per sec. per volt per cm. The apparatus used for the measurements was similar to that used by Langevin. Great variations exist in the results of those who have made measurements of the slowly-moving ions. While Pollock came to the conclusion that, in addition to these ions and to the ions of high mobility, there exists a class of ions of intermediate mobility, McClelland and Kennedy, working in Dublin, found a sharp line of demarcation between the two. Moreover, the latter investigators found values ranging from 1.72 to 27.9 E. S. U. for the charge held per cubic meter by the slowly-moving ions, while Pollock found 2.56 E. S. U. as a maximum and 0.28 E. S. U. as a minimum value. Pollock's mean results for the numbers of positive and negative slowly-moving ions are

[1] GOCKEL, A.: Luftelektrische Beobachtungen im schweizerischen Mittelland, im Jura und in den Alpen. *Neue Denkschriften der Schweizerischen Naturforschenden Gesellschaft*, Vol. 54. No. 1, February 15, 1917.

1914 and 2228, respectively. On the other hand, Langevin found values of the order 10,000 in Paris. The smaller values are in harmony with the author's measurements, and the high values obtained by McClelland and Kennedy, and by Langevin, are attributed to the influence of the industrial centers in which they worked. The means of all the author's measurements give 1.15 E. S. U. per cubic meter for the negative, and 1.16 for the positive ions; the ratio of the number of large ions to the number of small ions is of the order 2 or 3 instead of about 50 as found by Langevin in Paris. The author considers that the slowly-moving ions are charged dust-particles, and are in part identical with the nuclei measured in Aitken's dust-counter.

From a knowledge of the total charges contained on the positive and negative ions respectively, the corresponding volume density of charge (ρ_+ or ρ_-) may be obtained by subtraction. It may also be obtained as in Daunderer's method by measuring the vertical space derivative of the potential-gradient. The author's mean values for ρ_+ and ρ_-, found by the former method, are considerably smaller than those found by Daunderer in Bad Aibling, but the differences are considered to be real, and not attributable to difference in method of measurement.

Measurements of the actual number of dust particles are dealt with in Section 4. Measurements of the number of nuclei were made at 8^h a. m., and 2^h p. m., from August, 1914, to May, 1916. Tables of the monthly mean values are given, as also a set of observations illustrating the diurnal variation and based on observations taken throughout a period of 7 days. In summer the maximum number of nuclei is found about 7^h a. m. On the other hand, in winter, the maximum is reached about 10^h a. m.

In those cases where mid-day precipitation occurs, there are usually found an abnormally high number of nuclei (100,000 or more) in the morning, so that when low values of the nuclei are found in the morning, one can usually count upon absence of precipitation at least until the evening. The conclusions in this respect, with regard to the condensation nuclei apply also as a general rule to the slowly-moving ions.

As the result of measurements made in various localities, it is concluded that products of combustion, and not mineral dust, are the chief source of condensation nuclei. The following data illustrate the mean numbers of nuclei found per cubic centimenter in different localities: Halle, 45,000; Freiburg, 83,000; Gersau, 2,480; Weissenstein, 12,500; Lesser Scheideck, 1,870; Eggishorn, 500; Aletsch Glacier, 500.

In so far as the slowly-moving ions are produced by combination of small ions with nuclei, the small negative ions will, on account of their higher mobility, be absorbed more readily than the small positive ions. This accounts in part for the excess of positive over negative ionization as measured by the Ebert ion-counter, and shows that the excess is not entirely attributable to the influence of the potential-gradient. [See Sec. 5.]

The author favors Lenard's view, that the slowly-moving ions result in a great measure as a consequence of the absorption of ions by products of combustion, and by volcanic dust, as distinct from Langevin's

assumption that they are water particles to which ions have attached themselves. [See Sec. 5.]

In Section 6 the author points out that Pollock's conclusion *that the number of ions of intermediate velocity should increase with the vapor pressure is contrary to experimental results,* and he suggests that the difference between the intermediate and slowly-moving ions is one of degree rather than kind. In support of this conclusion data are quoted showing that the numbers of intermediate ions go hand in hand with the number of condensation nuclei as measured by Aitken's dust-counter.

Section 7 contains a *discussion of the effect of the Earth's electrical field in influencing measurements made with the Ebert ion-counter.* Thus, for example, the author finds marked increase of the ratio of the positive to negative ionization when measurements are made on the top of a tower. The *conductivity* was measured by observing the electrical dispersion from a horizontal charged wire 80 cm. long, mounted on a balcony and shielded from the Earth's field by wire netting. The mean specific ionic velocities as calculated from the observed ionic contents and conductivities were $v_+ = 0.94$ and $v_- = 0.97$ cm. per sec. per volt per cm. A table is given illustrating the dependence of conductivity upon the numbers of dust nuclei, and showing values ranging from 1.44×10^{-4} and 1.30×10^{-4} E. S.U., for λ_+ and λ_- respectively, for a case where the number of nuclei per c.c. was of the order 500-2,000, to values 0.77×10^{-4} and 0.81×10^{-4} for a case where the number of nuclei was of the order of 30,000 per c.c.

In Section 8 are given *monthly mean values for the ionic content,* based upon observations taken between October, 1913, and May, 1916. These show higher values for the summer than for the winter months. The most marked phenomenon in the daily variation of the ionic density and conductivity is the lowering of these elements during the morning as a result of rising mist layers. Between 1 and 5 p. m. (or 6 p. m. in summer), the conductivity remains sensibly constant; towards sundown it decreases, and afterwards stays at its mean value. Experiments made with the object of determining whether sudden variations of the potential-gradient are accompanied by, and are attributable to sudden changes of the conductivity gave no support to this view.

Section 9 contains the results of *measurements made on mountains,* and it contains quotations and comparisons with the results of other observers The observations were made on rain-free hours between July and September, in 1913, 1914, and 1915. Table 1 summarizes the results, i_+ and i_- referring to the charges contained per cubic meter of air, and λ_+ and λ_- to the conductivities.

Observations made in the Jura and on Lake Lucerne are quoted in Section 10.

In Section 11 are described *measurements of the coefficeint of ionic recombination, by Schuster's method.* The mean value obtained at Freiburg was $\alpha = 2.28 \times 10^{-6}$. The values obtained showed considerable dependence upon the locality, and in this respect were found to vary in the opposite direction to the ionic-densities. It is pointed out, however,

Table I.—*Showing the Influence of Mountainous Conditions on the Conductivity and Ionic-Content.*

PLACE	i_+	i_-	λ_+	λ_-
	(E. S. U.)		(E. S. U. $\times 10^{-4}$)	
Freiburg	0.483	0.433	1.30	1.22
Scheidegg	0.679	0.500	....	....
Eggishorn	0.881	0.581	4.65	2.99
Aletsch Glacier	1.368	0.873	....	....
Ridge of the Jungfrau	0.718	0.422	3.50	2.46

that the coefficient of recombination as here measured is by no means the same quantity as that which determines the rate of disappearance of small ions in the atmosphere, where the charged and uncharged nuclei play an important part in the phenomenon.

The *measurements of the penetrating radiation* described in Section 12 were made with Wulf's apparatus. No diurnal variation was observed, either in the open air or in a cellar. On the other hand, there was a marked annual variation in the open. The minimum fell in February, with an average of 10.7 ions per c.c. per sec., and the maximum in June, with an average of 12.2 ions per c.c. per sec. From September to November there was no appreciable change. Observations made at an altitude of 3,190 meters showed no apparent increase in the diurnal variation.

Measurements of the effusion of ions from the ground are described in Section 13. From freshly-dug garden-soil the effusion was about double that from ground covered with short grass, smaller from hard molassic rock, insignificant in the case of water-laden soil, and stronger in a forest clearing than in a space surrounded by trees.

Measurements of the potential-gradient have been carried out for two years with a polonium collector. The diurnal-variation curves show the usual characteristics. The absolute values are smaller in summer than in winter and the mid-day depression is less pronounced. The mean daily amplitude forms 76 per cent of the monthly mean value in July, and 111 per cent in February. [See Sec. 14.]

The mean value of the *vertical conduction current-density* as calculated from the conductivity and potential-gradient is 9×10^{-7} E. S. U. per square centimeter. The annual variation of the conduction current shows a minimum in June and a maximum in February. [See Sec. 14.]

In Section 15 are cited *measurements of ionic content and conductivity made during rain.* During heavy rain the conductivity is smaller than during light rain, and rain of long duration results in small conductivity. During summer rain of the storm character, even when thunder was inaudible, high values were always found. Since high values of conductivity and ionic content may be observed during light rain, one sees that the increased ionization is not due entirely to the Lenard effect, especially as the conductivity does not change appreciably during intermittence of the rainfall. The increase of ionization accompanying rain is not confined to the immediate neighborhood of the rainfall but may be observed when the rainfall occurs at a distance of some kilometers.

PRELIMINARY RESULTS OF OCEAN MAGNETIC OBSERVATIONS ON THE CARNEGIE FROM SAN FRANCISCO TO EASTER ISLAND AND BUENOS AIRES, NOVEMBER 1916—MARCH 1917.[1]

By J. P. Ault, Commanding the *Carnegie*.

Observers: J. P. Ault, commanding the *Carnegie*: H. M. W. Edmonds, B. Jones, A. D. Power, L. L. Tanguy, and N. Meisenhelter.

Date	Latitude	Long. East of Gr.	Carnegie Values			Chart Corrections[2]		
			Decl'n	Incl'n	Hor. Int.	Brit.	Ger.	U. S.
1916	° ′	° ′	°	°	c.g.s.	°	°	°
Nov. 2	36 06 N	236 41	17.1 E	....	......	0.3W	0.1 E	0.2W
2	35 46 N	236 45	....	60.1 N	.259	0.4 S	0.4 N	......
2	35 42 N	236 46	17.1 E	....	......	0.1W	0.3 E	0.0
3	35 22 N	236 14	16.9 E	....	......	0.1W	0.4 E	0.0
3	35 10 N	236 05	....	59.4 N	.261	0.6 S	0.6 N	......
3	34 59 N	236 07	16.7 E	....	......	0.1W	0.3 E	0.1W
4	34 24 N	236 17	16.2 E	....	......	0.3W	0.1 E	0.3W
4	33 56 N	236 36	....	58.3 N	.268	0.1 S	0.9 N	......
5	32 14 N	237 03	15.5 E	....	......	0.2 E	0.3 E	0.2W
5	31 20 N	237 10	....	55.9 N	.280	0.3 N	0.9 N	......
5	31 04 N	237 10	15.1 E	....	......	0.1 E	0.5 E	0.3W
6	29 45 N	238 05	14.2 E	....	......	0.3W	0.1 E	0.7W
6	28 58 N	238 33	....	53.6 N	.287	0.9 N	0.7 N	......
6	28 46 N	238 40	14.4 E	....	......	0.2 E	0.7 E	0.1 E
7	27 16 N	239 43	13.4 E	....	......	0.3W	0.4 E	0.1W
7	26 25 N	240 11	....	50.8 N	.298	1.0 N	0.6 N	......
7	26 12 N	240 18	12.9 E	....	......	0.3W	0.3 E	0.2W
8	24 20 N	241 25	12.4 E	....	......	0.3W	0.6 E	0.2W
8	23 21 N	241 57	....	47.5 N	.309	0.5 N	1.5 N	......
8	23 06 N	242 05	11.7 E	....	......	0.6W	0.4 E	0.6W
9	21 19 N	243 08	11.1 E	....	......	0.5W	0.4 E	0.6W
9	20 53 N	243 19	....	44.5 N	.316	0.3 N	1.3 N	......
9	20 47 N	243 22	10.7 E	....	......	0.6W	0.2 E	0.8W
10	20 16 N	243 41	10.6 E	....	......	0.6W	0.2 E	0.8W
10	19 59 N	243 49	....	43.0 N	.321	0.4 S	0.8 N	......
10	19 55 N	243 50	10.9 E	....	......	0.2W	0.6 E	0.4W
11	19 36 N	243 51	10.8 E	....	......	0.2W	0.6 E	0.3W
11	19 28 N	243 54	....	42.3 N	.322	0.4 S	1.1 N	......
11	19 26 N	243 55	10.7 E	....	......	0.3W	0.6 E	0.4W
12	19 00 N	244 15	10.4 E	....	......	0.5W	0.4 E	0.6W
12	18 31 N	244 26	....	41.1 N	.325	0.6 S	0.9 N	......
12	18 23 N	244 26	10.1 E	....	......	0.7W	0.1 E	0.8W
13	17 02 N	244 38	10.2 E	....	......	0.2W	0.6 E	0.3W
13	16 33 N	244 39	....	38.1 N	.330	0.5 S	1.7 N	......
13	16 22 N	244 40	10.0 E	....	......	0.3W	0.6 E	0.3W
14	14 47 N	244 56	....	35.2 N	.334	0.5 S	1.6 N	......
14	14 46 N	244 56	9.6 E	....	......	0.2W	0.4 E	0.6W
14	14 39 N	244 56	9.6 E	....	......	0.2W	0.4 E	0.5W
15	14 17 N	244 56	9.6 E	....	......	0.1W	0.4 E	0.3W
15	14 10 N	244 56	....	34.3 N	.335	0.7 S	2.0 N	......

[1] For previous table, see *Terr. Mag.*, v. 21, pp. 175–176.

[2] Charts used for comparison: U. S. Hydrographic Office Chart No. 2406 for 1915; British Admiralty Charts No. 2598 for 1912, and No. 3598 for 1907; Reichs-Marine-Amt Charts Tit. XIV, No. 2 for 1910, Tit. XIV, No. 2a for 1905.

Date	Latitude	Long. East of Gr.	Carnegie Values			Chart Corrections[2]		
			Decl'n	Incl'n	Hor. Int.	Brit.	Ger.	U. S.
1916	° ′	° ′	°	°	c.g.s.	°	°	°
Nov. 15	14 01 N	244 57	9.5 E	....	......	0.1W	0.3 E	0.3W
16	12 54 N	244 52	9.3 E	....	......	0.0	0.2 E	0.2W
16	12 02 N	245 01	....	30.6 N	.338	1.0 S	1.9 N	......
16	11 45 N	245 06	9.2 E	....	......	0.2 E	0.3 E	0.0
17	10 09 N	245 57	9.0 E	....	......	0.2 E	0.2 E	0.0
17	9 21 N	246 31	....	26.1 N	.340	0.9 S	3.0 N	......
17	9 10 N	246 37	8.7 E	....	......	0.0	0.1 E	0.3W
18	8 48 N	246 39	8.9 E	....	......	0.3 E	0.3 E	0.0
18	8 54 N	246 26	....	25.3 N	.342	0.7 S	3.1 N	......
18	8 54 N	246 30	8.9 E	....	......	0.3 E	0.3 E	0.1W
19	8 53 N	247 22	....	25.6 N	.341	0.6 S	3.2 N	......
19	8 48 N	247 30	8.9 E	....	......	0.3 E	0.4 E	0.0
20	8 00 N	248 28	8.8 E	....	......	0.3 E	0.4 E	0.0
20	7 46 N	248 39	....	23.7 N	.342	0.8 S	3.5 N	......
20	7 42 N	248 43	8.8 E	....	......	0.4 E	0.4 E	0.0
21	7 42 N	248 55	8.8 E	....	......	0.4 E	0.4 E	0.0
21	7 34 N	249 46	....	23.6 N	.342	0.9 S	3.7 N	......
22	7 32 N	250 22	8.9 E	....	......	0.5 E	0.7 E	0.1W
22	7 28 N	250 46	....	23.6 N	.343	0.9 S	3.6 N	......
23	7 15 N	251 05	8.9 E	....	......	0.5 E	0.7 E	0.1W
23	7 10 N	251 15	....	23.2 N	.342	1.0 S	3.6 N	......
24	7 06 N	250 36	9.0 E	....	......	0.6 E	0.8 E	0.0
24	7 00 N	251 16	....	23.1 N	.342	0.5 S	4.1 N	......
25	6 52 N	252 49	8.7 E	....	......	0.5 E	0.7 E	0.3W
25	6 52 N	253 13	....	23.1 N	.343	0.5 S	3.7 N	......
26	6 21 N	253 31	9.1 E	....	......	1.0 E	1.1 E	0.1 E
26	6 11 N	253 15	....	21.8 N	.342	0.4 S	3.6 N	......
27	5 37 N	252 19	9.0 E	....	......	0.9 E	0.9 E	0.0
27	5 22 N	251 41	....	19.9 N	.343	0.7 S	3.9 N	......
28	5 07 N	249 52	8.8 E	....	......	0.7 E	0.6 E	0.1W
28	5 04 N	249 06	....	18.7 N	.343	1.1 S	3.8 N	......
28	4 56 N	248 27	8.7 E	....	......	0.6 E	0.3 E	0.1W
29	4 28 N	247 37	8.8 E	....	......	0.6 E	0.4 E	0.0
29	3 52 N	246 46	....	16.1 N	.340	0.8 S	3.9 N	......
29	3 43 N	246 30	8.8 E	....	......	0.6 E	0.3 E	0.1 E
30	2 25 N	244 35	8.4 E	....	......	0.2 E	0.2W	0.3W
30	1 40 N	243 19	....	10.8 N	.339	1.8 S	3.1 N	......
30	1 22 N	242 56	8.6 E	....	......	0.3 E	0.0	0.1W
Dec. 1	0 06 N	241 39	8.4 E	....	......	0.1 E	0.1W	0.3W
1	0 27 S	241 24	....	6.3 N	.338	2.2 S	2.6 N	......
1	0 42 S	241 16	8.5 E	....	......	0.2 E	0.0	0.2W
2	1 19 S	240 53	8.3 E	....	......	0.1W	0.2W	0.5W
2	1 29 S	240 41	....	3.9 N	.338	3.1 S	1.9 N	......
2	1 40 S	240 36	8.4 E	....	......	0.0	0.1W	0.4W
3	2 05 S	240 08	8.6 E	....	......	0.2 E	0.0	0.2W
3	2 29 S	239 54	....	1.9 N	.337	3.3 S	2.1 N	......
3	2 44 S	239 48	8.5 E	....	......	0.0	0.2W	0.4W
4	3 55 S	239 16	8.5 E	....	......	0.1W	0.3W	0.4W
4	4 41 S	238 55	....	2.7 S	.335	4.5 S	1.9 N	......
4	4 57 S	238 43	8.7 E	....	......	0.1W	0.1W	0.3W
5	6 20 S	237 27	8.7 E	....	......	0.3W	0.1W	0.3W
5	7 08 S	236 42	....	7.6 S	.333	5.0 S	1.7 N	......
5	7 25 S	236 26	8.9 E	....	......	0.2W	0.0	0.2W
6	9 02 S	235 12	9.0 E	....	......	0.4W	0.0	0.3W

Date	Latitude	Long. East of Gr.	Carnegie Values			Chart Corrections[2]		
			Decl'n	Incl'n	Hor. Int.	Brit.	Ger.	U. S.
1916	° ′	° ′	°	°	c.g.s.	°	°	°
Dec. 6	10 02 S	234 54	....	13.6 S	.332	6.4 S	1.7 N	......
6	10 21 S	234 48	9.3 E	....	......	0.2W	0.2 E	0.1W
7	12 00 S	234 34	9.4 E	....	......	0.5W	0.1 E	0.3W
7	12 54 S	234 26	....	19.0 S	.328	7.0 S	1.2 N	......
7	13 20 S	234 21	9.8 E	....	......	0.3W	0.3 E	0.0
8	15 11 S	234 09	9.8 E	....	......	0.6W	0.0	0.3W
8	16 00 S	234 12	....	24.6 S	.324	6.0 S	1.3 N	......
8	16 10 S	234 12	10.0 E	....	......	0.6W	0.0	0.3W
9	17 19 S	234 02	10.3 E	....	......	0.5W	0.1 E	0.2W
9	18 06 S	233 50	....	28.0 S	.322	5.4 S	1.9 N	......
9	18 26 S	233 45	10.7 E	....	......	0.3W	0.4 E	0.1W
10	19 51 S	233 24	10.9 E	....	......	0.3W	0.4 E	0.2W
10	20 26 S	233 15	....	31.6 S	.318	4.8 S	2.0 N	......
10	20 38 S	233 14	11.1 E	....	......	0.3W	0.4 E	0.2W
11	21 50 S	233 27	11.4 E	....	......	0.2W	0.4 E	0.2W
11	22 33 S	233 32	....	34.6 S	.316	4.4 S	2.4 N	......
11	22 51 S	233 35	11.5 E	....	......	0.3W	0.2 E	0.3W
12	24 14 S	233 56	11.9 E	....	......	0.1W	0.2 E	0.2W
12	25 05 S	234 11	....	38.3 S	.312	5.4 S	2.4 N	......
12	25 20 S	234 24	12.5 E	....	......	0.3 E	0.4 E	0.1 E
13	26 13 S	235 13	12.4 E	....	......	0.1W	0.1W	0.3W
13	26 36 S	235 42	....	39.7 S	.308	5.7 S	2.6 N	......
13	26 42 S	235 48	12.2 E	....	......	0.4W	0.5W	0.6W
14	27 11 S	236 28	12.8 E	....	......	0.1 E	0.2W	0.1W
14	27 25 S	236 48	....	40.9 S	.306	6.3 S	2.3 N	......
14	27 28 S	236 53	12.8 E	....	......	0.1W	0.2W	0.3W
15	27 45 S	237 11	13.4 E	....	......	0.4 E	0.2 E	0.2 E
15	27 56 S	237 31	....	41.4 S	.304	6.4 S	2.4 N	......
15	28 01 S	237 37	13.2 E	....	......	0.2 E	0.0	0.1W
16	28 40 S	238 13	13.6 E	....	......	0.4 E	0.1 E	0.1 E
16	29 06 S	238 43	....	42.7 S	.302	6.7 S	2.8 N	......
16	29 15 S	238 54	13.5 E	....	......	0.0	0.4W	0.2W
17	29 56 S	239 42	13.8 E	....	......	0.1 E	0.3W	0.1W
17	30 31 S	240 42	....	44.1 S	.300	7.3 S	2.5 N	......
17	30 32 S	241 16	14.8 E	....	......	0.7 E	0.1 E	0.4 E
18	31 35 S	242 18	14.8 E	....	......	0.2 E	0.5W	0.1W
18	31 45 S	243 06	....	45.0 S	.296	7.2 S	2.2 N	......
18	31 39 S	243 24	14.8 E	....	......	0.0	0.7W	0.4W
18	31 42 S	243 37	15.4 E	....	......	0.5 E	0.2W	0.1 E
19	31 59 S	244 43	15.7 E	....	......	0.5 E	0.2W	0.2 E
19	32 16 S	245 39	....	45.2 S	.294	7.2 S	2.4 N	......
19	32 24 S	246 00	15.2 E	....	......	0.2W	1.1W	0.7W
20	32 33 S	247 05	15.2 E	....	......	0.3W	1.3W	1.0W
20	32 12 S	248 43	....	44.5 S	.292	7.2 S	2.6 N	......
20	32 06 S	248 58	16.1 E	....	......	0.4 E	0.8W	0.2W
21	31 18 S	250 29	15.6 E	....	......	0.1 E	1.4W	0.6W
21	30 55 S	251 06	....	43.2 S	.293	7.9 S	2.0 N	......
21	30 46 S	251 14	16.8 E	....	......	1.4 E	0.1W	0.8 E
22	30 40 S	251 08	16.4 E	....	......	1.0 E	0.4W	0.5 E
22	30 36 S	251 11	....	41.9 S	.296	6.9 S	3.0 N	......
22	30 42 S	251 20	16.9 E	....	......	1.4 E	0.0	0.9 E
23	30 48 S	251 26	15.6 E	....	......	0.1 E	1.1W	0.3W
23	30 05 S	251 25	....	41.2 S	.295	6.6 S	3.2 N	......
23	29 42 S	251 24	15.2 E	....	......	0.1 E	1.3W	0.5W
24	27 57 S	251 20	14.5 E	....	......	0.1 E	1.4W	0.6W

Date	Latitude	Long. East of Gr.	Carnegie Values			Chart Corrections[2]		
			Decl'n	Incl'n	Hor. Int.	Brit.	Ger.	U. S.
	° ′	° ′	°	°	c.g.s.	°	°	°
1917 Jan. 2	27 08 S	250 34	12.6 E*	......	......	1.3W	2.9W	2.1W
2	26 38 S	250 12	......	37.6 S	.299	6.3 S	2.4 N	......
2	26 29 S	250 07	13.6 E	......	......	0.1 E	1.6W	0.8W
3	25 05 S	249 17	13.0 E	......	......	0.0	1.6W	0.8W
3	23 58 S	248 58	......	34.5 S	.304	6.1 S	1.9 N	......
3	23 35 S	248 55	12.5 E	......	......	0.0	1.4W	0.6W
4	22 07 S	248 45	12.3 E	......	......	0.3 E	1.3W	0.0
4	21 05 S	248 52	......	30.3 S	.306	6.1 S	2.0 N	......
4	20 41 S	248 51	12.3 E	......	......	0.5 E	0.7W	0.4 E
5	18 50 S	248 34	11.3 E	......	......	0.2W	1.2W	0.1W
5	17 54 S	248 40	......	25.0 S	.312	6.2 S	1.4 N	......
5	17 28 S	248 44	11.0 E	......	......	0.3W	1.0W	0.2W
6	15 34 S	248 56	10.4 E	......	......	0.6W	1.0W	0.4W
6	14 45 S	248 51	......	19.6 S	.318	6.8 S	1.9 N	......
6	14 23 S	248 52	10.9 E	......	......	0.1 E	0.2W	0.4 E
7	12 31 S	248 54	10.0 E	......	......	0.4W	0.6W	0.1W
7	12 29 S	248 23	......	15.7 S	.321	7.0 S	2.0 N	......
7	12 29 S	248 04	10.9 E	......	......	0.5 E	0.4 E	0.8 E
8	12 30 S	246 37	9.7 E	......	......	0.7W	0.6W	0.3W
8	12 30 S	245 31	......	16.3 S	.322	7.2 S	1.8 N	......
8	12 31 S	245 08	9.9 E	......	......	0.4W	0.3W	0.1W
9	12 33 S	243 34	9.6 E	......	......	0.7W	0.4W	0.4W
9	12 34 S	242 38	......	17.0 S	.322	7.4 S	1.7 N	......
9	12 35 S	242 13	9.7 E	......	......	0.5W	0.3W	0.2W
10	12 36 S	240 26	9.6 E	......	......	0.5W	0.3W	0.3W
10	12 36 S	239 24	......	17.8 S	.325	7.2 S	1.4 N	......
10	12 36 S	239 05	9.5 E	......	......	0.6W	0.2W	0.3W
11	12 40 S	237 23	9.3 E	......	......	0.8W	0.3W	0.5W
11	12 55 S	236 27	......	18.4 S	.325	6.7 S	1.8 N	......
11	13 10 S	236 12	10.0 E	......	......	0.1W	0.3 E	0.2 E
12	14 06 S	234 54	9.9 E	......	......	0.4W	0.2 E	0.0
12	14 40 S	234 16	......	22.0 S	.325	6.0 S	1.3 N	......
12	14 53 S	234 03	10.2 E	......	......	0.2W	0.5 E	0.2 E
13	15 48 S	233 06	10.0 E	......	......	0.5W	0.0	0.1W
13	16 08 S	232 38	......	24.9 S	.324	5.6 S	1.5 N	......
13	16 21 S	232 23	10.3 E	......	......	0.3W	0.3 E	0.1 E
14	16 59 S	231 46	10.7 E	......	......	0.0	0.6 E	0.3 E
14	17 42 S	231 09	......	27.8 S	.322	5.3 S	1.4 N	......
15	19 35 S	230 06	10.8 E	......	......	0.2W	0.4 E	0.2W
15	19 36 S	230 02	......	30.8 S	.321	4.2 S	1.9 N	......
16	19 38 S	229 49	10.7 E	......	......	0.3W	0.3 E	0.3W
16	19 42 S	229 46	......	31.2 S	.320	4.2 S	1.7 N	......
16	19 42 S	229 45	10.7 E	......	......	0.3W	0.3 E	0.3W
17	19 58 S	229 18	11.2 E	......	......	0.2 E	0.8 E	0.1 E
17	20 18 S	228 54	......	32.1 S	.320	4.0 S	1.9 N	......
18	21 21 S	227 31	11.5 E	......	......	0.2 E	1.0 E	0.3 E
18	21 48 S	226 48	......	34.9 S	.320	4.2 S	1.7 N	......
18	21 55 S	226 29	11.6 E	......	......	0.2 E	1.1 E	0.1 E
19	22 53 S	225 18	11.7 E	......	......	0.1 E	1.0 E	0.0
19	23 55 S	224 58	......	37.9 S	.315	4.8 S	1.6 N	......
19	24 24 S	224 51	12.0 E	......	......	0.1 E	1.1 E	0.0
20	26 08 S	223 56	12.4 E	......	......	0.2 E	1.2 E	0.0
20	27 01 S	223 14	......	42.8 S	.311	6.0 S	1.4 N	......
20	27 22 S	223 01	12.8 E	......	......	0.3 E	1.4 E	0.0

* Local Disturbance.

Date	Latitude	Long. East of Gr.	Carnegie Values			Chart Corrections[2]		
			Decl'n	Incl'n	Hor. Int.	Brit.	Ger.	U. S.
1917	° ′	° ′	°	°	c.g.s.	°	°	°
Jan. 21	28 53 S	221 43	12.8 E	....	......	0.0	1.1 E	0.3W
21	29 53 S	220 53	....	46.5 S	.305	6.5 S	1.1 N	......
21	30 20 S	220 37	13.6 E	....	......	0.5 E	1.6 E	0.1 E
22	31 54 S	220 29	13.8 E	....	......	0.2 E	1.4 E	0.1W
22	32 31 S	220 19	....	49.6 S	.299	6.4 S	0.8 N	......
23	35 05 S	219 54	....	52.6 S	.290	5.8 S	0.5 N	......
23	35 19 S	219 46	14.7 E	....	......	0.3 E	1.4 E	0.0
24	37 15 S	218 15	14.5 E	....	......	0.3W	0.7 E	0.6W
24	37 22 S	218 00	....	55.2 S	.283	5.7 S	0.4 N	......
25	37 31 S	217 16	15.2 E	....	......	0.4 E	1.4 E	0.1 E
25	37 37 S	217 06	....	55.6 S	.281	5.4 S	0.1 N	......
26	37 47 S	216 09	....	55.8 S	.282	5.1 S	0.2 N	......
27	37 52 S	215 23	15.3 E	....	......	0.5 E	1.5 E	0.0
27	37 53 S	215 48	....	55.9 S	.280	5.0 S	0.2 N	......
27	37 54 S	216 06	15.4 E	....	......	0.5 E	1.6 E	0.1 E
28	37 47 S	216 54	15.4 E	....	......	0.5 E	1.6 E	0.1 E
28	37 45 S	217 37	....	55.6 S	.282	5.3 S	0.2 N	......
28	37 36 S	218 13	15.4 E	....	......	0.5 E	1.5 E	0.1 E
29	38 08 S	219 20	15.6 E	....	......	0.6 E	1.3 E	0.2 E
29	38 29 S	220 32	....	55.4 S	.281	4.7 S	0.8 N	......
29	38 31 S	220 48	15.8 E	....	......	0.6 E	1.3 E	0.2 E
30	38 34 S	221 37	16.0 E	....	......	0.7 E	1.5 E	0.3 E
30	38 31 S	221 44	....	55.6 S	.281	5.4 S	0.6 N	......
30	38 31 S	221 46	16.2 E	....	......	1.0 E	1.7 E	0.6 E
31	38 59 S	222 10	16.0 E	....	......	0.6 E	1.4 E	0.1 E
31	39 47 S	222 25	....	56.9 S	.275	5.1 S	0.3 N	......
31	40 05 S	222 25	16.6 E	....	......	0.8 E	1.5 E	0.0
Feb. 1	41 21 S	222 11	17.0 E	....	......	0.7 E	1.5 E	0.1W
1	42 16 S	221 53	....	59.1 S	.268	4.1 S	0.3 N	......
1	42 31 S	221 44	17.4 E	....	......	0.7 E	1.6 E	0.1W
2	43 41 S	221 17	18.0 E	....	......	0.9 E	1.8 E	0.1 E
2	43 36 S	221 45	....	60.3 S	.263	3.5 S	0.2 N	......
3	42 58 S	224 40	17.4 E	....	......	0.3 E	1.0 E	0.4W
3	42 27 S	226 03	....	58.7 S	.270	4.8 S	0.5 N	......
3	42 21 S	226 17	17.5 E	....	......	0.5 E	1.2 E	0.2W
4	42 49 S	228 00	18.4 E	....	......	1.2 E	1.8 E	0.5 E
4	43 24 S	229 04	....	58.9 S	.270	4.3 S	0.8 N	......
4	43 41 S	229 35	18.5 E	....	......	0.8 E	1.2 E	0.1 E
5	44 53 S	231 49	19.5 E	....	......	1.2 E	1.3 E	0.4 E
5	45 24 S	232 51	....	59.9 S	.264	3.6 S	0.8 N	......
5	45 42 S	233 29	20.2 E	....	......	1.4 E	1.4 E	0.5 E
6	46 24 S	235 19	20.6 E	....	......	1.3 E	1.1 E	0.2 E
6	46 28 S	237 16	....	60.2 S	.262	3.6 S	0.8 N	......
6	46 27 S	237 57	21.5 E	....	......	2.0 E	1.3 E	0.6 E
7	46 46 S	240 58	21.7 E	....	......	1.8 E	0.8 E	0.0
7	47 08 S	241 44	....	59.9 S	.262	3.9 S	0.9 N	......
7	47 16 S	242 00	21.7 E	....	......	1.5 E	0.3 E	0.6W
8	49 12 S	244 29	....	61.0 S	.259	3.2 S	0.8 N	......
8	49 30 S	244 54	24.2 E	....	......	2.3 E	1.0 E	0.0
9	52 14 S	248 13	....	62.1 S	.253	1.7 S	1.1 N	......
10	54 10 S	252 45	....	62.3 S	.252	0.8 S	1.4 N	......
11	54 33 S	257 14	27.6 E	....	......	0.1W	1.2W	0.8W
11	54 41 S	258 40	....	61.0 S	.257	0.5 S	1.6 N	......
11	54 43 S	259 01	29.1 E	....	......	1.2 E	0.0	0.8 E
11	54 46 S	259 31	28.1 E	....	......	0.2 E	1.1W	0.3W

Date	Latitude	Long. East of Gr.	Carnegie Values			Chart Corrections[2]		
			Decl'n	Incl'n	Hor. Int.	Brit.	Ger.	U. S.
1917	° ′	° ′	°	°	c.g.s.	°	°	°
Feb. 12	55 07 S	263 14	28.0 E	....	......	0.2 E	1.1W	0.0
12	55 24 S	265 18	....	59.3 S	.262	0.2 N	1.6 N	......
12	55 28 S	265 47	27.9 E	....	......	0.3 E	0.9W	0.2 E
12	55 30 S	266 04	28.3 E	....	......	0.8 E	0.3W	0.6 E
13	56 00 S	269 44	27.4 E	....	......	0.4 E	0.4W	0.4 E
13	56 16 S	272 08	....	57.7 S	.264	1.0 N	1.4 N	......
13	56 20 S	272 39	26.7 E	....	......	0.3 E	0.3W	0.4 E
14	56 43 S	275 48	25.6 E	....	......	0.0	0.4W	0.1W
14	56 56 S	277 48	....	56.5 S	.267	1.3 N	1.0 N	......
15	57 34 S	282 49	22.8 E	....	......	0.3W	0.4W	0.5W
15	57 34 S	284 02	....	55.3 S	.267	1.2 N	0.8 N	......
15	57 31 S	284 29	22.4 E	....	......	0.0	0.0	0.0
15	57 28 S	284 52	21.8 E	....	......	0.4W	0.2W	0.4W
16	56 58 S	288 26	20.5 E	....	......	0.0	0.9 E	0.5 E
16	56 54 S	288 50	19.2 E	....	......	1.0W	0.1W	0.6W
16	56 52 S	289 07	19.9 E	....	......	0.2W	0.7 E	0.4 E
16	56 40 S	290 23	....	52.8 S	.268	0.9 N	1.0 N	......
16	56 37 S	290 51	18.5 E	....	......	0.7W	0.2 E	0.1 E
16	56 35 S	291 18	18.3 E	....	......	0.7W	0.3 E	0.3 E
17	56 05 S	293 34	17.6 E	....	......	0.5 E	1.1 E	1.1 E
17	55 53 S	294 07	....	51.4 S	.268	0.5 N	0.8 N	......
17	55 50 S	294 18	16.5 E	....	......	0.1 E	0.7 E	0.4 E
17	55 37 S	294 53	16.0 E	....	......	0.0	0.5 E	0.2 E
18	55 18 S	295 47	15.2 E	....	......	0.1 E	0.3 E	0.2 E
18	55 03 S	295 51	....	50.1 S	.267	0.7 N	1.0 N	......
19	53 34 S	296 54	14.1 E	....	......	0.4 E	0.4 E	0.3 E
19	53 28 S	296 54	....	48.7 S	.265	0.4 N	0.6 N	......
20	52 26 S	295 42	14.4 E	....	......	0.4 E	0.1 E	0.3 E
20	52 12 S	296 17	....	47.3 S	.265	0.6 N	0.9 N	......
20	52 03 S	296 45	13.5 E	....	......	0.2 E	0.2 E	0.1 E
21	50 48 S	298 00	12.4 E	....	......	0.4 E	0.1 E	0.3 E
21	49 50 S	298 51	....	44 5 S	.262	0.8 N	0.8 N	......
21	49 41 S	298 59	11.5 E	....	......	0.7 E	0.3 E	0.4 E
22	48 02 S	299 57	10.4 E	....	......	0.7 E	0.2 E	0.3 E
22	47 49 S	300 04	....	42.2 S	.260	1.1 N	0.8 N	......
22	47 32 S	300 12	10.0 E	....	......	0.7 E	0.2 E	0.1 E
23	46 38 S	300 27	9.6 E	....	......	0.6 E	0.4 E	0.2 E
23	46 10 S	300 29	....	40.4 S	.259	1.4 N	1.0 N	......
23	45 59 S	300 30	9.3 E	....	......	0.6 E	0.2 E	0.2 E
24	45 48 S	300 56	8.9 E	....	......	0.5 E	0.2 E	0.1 E
24	45 26 S	301 02	....	39.6 S	.257	1.5 N	1.0 N	......
25	43 08 S	301 51	....	37.3 S	.253	1.7 N	0.6 N	......
26	40 30 S	302 46	5.8 E	....	......	0.3 E	0.0	0.1 E
26	39 41 S	303 09	....	33.5 S	.248	1.0 N	0.3 N	......
26	39 26 S	303 19	5.2 E	....	......	0.4 E	0.3 E	0.1 E
27	38 29 S	303 55	4.3 E	....	......	0.3 E	0.3 E	0.0
27	38 09 S	304 06	....	31.6 S	.246	1.0 N	0.1 N	......
27	38 06 S	304 08	4.0 E	....	......	0.3 E	0.2 E	0.1 E
28	37 37 S	304 25	3.5 E	....	......	0.2 E	0.1 E	0.1 E
28	36 58 S	304 33	....	30.3 S	.245	0.8 N	0.1 N	......
28	36 43 S	304 32	3.3 E	....	......	0.3 E	0.3 E	0.3 E
Mar. 1	35 28 S	303 49	3.3 E	....	......	0.1 E	0.0	0.1 E
1	35 09 S	303 13	....	28.2 S	.246	0.8 N	0.2 N	......
1	35 08 S	302 58	4.0 E	....	......	0.3 E	0.1 E	0.3 E
2	34 41 S	302 02	4.6 E	....	......	0.4 E	0.4W	0.1W

NOTES

5. *Earthquake in Samoa, June 25, 1917.* The following abstract is made from the report[1] by Commander J. M. Poyer, governor of American Samoa and commandant of the naval station at Tutuila, in a letter received by the U. S. Navy Department:

About 6:30 p.m., June 25, 1917, an earthquake and moderate tidal wave occurred here. Earthquakes are somewhat frequent here, but this was the severest one that has occurred, according to old residents. No one was injured. A few buildings on the island were injured, notably two churches, one in Leone and one in Pago Pago, which were so badly damaged that their further use is dangerous and has been forbidden. There was no damage at the naval station. The rise and fall of water in Pago Pago Bay exceeded that reported from Apia. The bay is much narrower at its head than at its mouth, with the result that at the head of the bay the water rose and fell between 5 and 6 feet above and below normal.

The observatory at Apia broadcasted the following information by wireless:

The observer here places the center of the disturbance about 75 miles southwest of Samoa and considers it was due to a submarine landslide. No serious damage done. Earthquake violent for about minute and a half, and minor shakes were experienced throughout the night at intervals. Tidal waves about 3 feet high were experienced on south coast of Savali, Upola, and Tutuila, causing minor damage but no loss of life.

6. *Principal Magnetic Storms Recorded at the Cheltenham Magnetic Observatory, January-June 1917.* The following data for the Cheltenham Observatory have been communicated by the Superintendent of the U. S. Coast and Geodetic Survey, the observer-in-charge being Mr. George Hartnell:

Latitude 38° 44′.0N; Longitude 76° 50′.5, or $5^h\ 07^m.4$ W. of Greenwich.

Greenwich Mean Time		Range		
Beginning 1917	Ending 1917	D (Declination)	H (Hor'l Intensity)	Z (Vert'l Intensity)
h m	h	′	γ	γ
Jan. 4, 5 04	Jan. 5, 10	47.8	244	350
June 24, 18 35	June 25, 2	31.6	222	95

7. *British Admiralty Curves of Equal Magnetic Variation 1917.* These up-to-date and admirably-executed charts appear in 3 sheets: No. 1, Atlantic Ocean; No. 2, Indian and Western Pacific Oceans; and No. 3, Eastern Pacific Ocean. The size of each sheet is 38.1 × 25.1 inches. Curves of approximate annual-changes are also shown on each sheet. The Charts have been published under the superintendence of Rear-Admiral J. F. Parry, Hydrographer, who, in his transmitting letter to the Director of the Department of Terrestrial Magnetism credits the

[1] Official Bulletin, Washington, D. C., v. I, No. 69, July 31, 1917 (4).

Department with having supplied the "principal part of the new information now shown on these Charts."

8. New Zealand Magnetic Observatory. During the visit of the *Carnegie* at Port Lyttelton, New Zealand, in November, 1915, Captain J. P. Ault was informed by Director Skey of the Christchurch Magnetic Observatory, that, owing to the effects from electric car-lines, a new magnetic observatory had been established at Amberley, a small town about 30 miles north of Christchurch. The new observatory was not yet in full operation at the time, but magnetograms of the three magnetic elements were being obtained. In order to connect properly the work of the two observatories, both were to be operated for a year or more.

9. Personalia. On June 12, 1917, the Honorary degree of D. Sc. was conferred by the University of Oxford on *Prof. Arthur Schuster,* who subsequently delivered the Halley Lecture on "Terrestrial Magnetism; its Past, Present, and Future." We regret to record the untimely death of *Prof. Kr. Birkeland,* at Tokyo on June 18, 1917. He was born Dec. 13, 1867, and had thus not quite reached the age of 50. A biographical sketch and portrait of our lamented colleague, who did so much to advance the subjects of terrestrial magnetism, polar lights, cosmical magnetism and electricity, will be found in this Journal, vol. 14, 1909, p. 84, and pl. vi. A sketch of Birkeland's life by Dr. Chree appears also in *Nature*, June 28, 1917, p. 349.

10. Corrigenda to Störmer's "Fifth Communication," Terr. Mag. vol. 21, 1916, pp. 153-156. Owing to necessary abridgment and omission of certain illustrations, some errors unfortunately crept into Störmer's Fifth Communication on the Results of the Aurora-Borealis Expedition of 1913.

p. 153, in 11th line from bottom, read: The computation of a photogram taken at $10^h\ 20^m$, already published in the *Astrophysical Journal* of Nov. 1913 (vol. 38, p. 311) gave the following altitudes in km:

p. 153, 6th line from bottom, replace "the above-mentioned" by "an".

p. 154, in 4th line below Fig. 1, read: The altitudes in km. of points along the lower border of the curtain at $10^h\ 46^m\ 22^s$ are:

p. 155, in 16th line from top, read: Along the right border of a ray near Vega at $9^h\ 08^m$ a series of . . .

p. 155, in 8th line from bottom, read: The altitudes of some points along the lower edge of the curtain at $12^h\ 43^m\ 20^s$ in km. are:

Plates XI and XII. The "explications are put on the wrong side of the photograph."

11. Corrigendum, vol. 22, 1917, pp. 44-47. Page 46 should have been p. 44. The correct order of reading the pages, as marked, is: 43, 46, 44, 45, 47.


Wm Bullock Clark

WILLIAM BULLOCK CLARK.

While Professor William Bullock Clark was chiefly known for his notable contributions to the advancement of geological science, he is also to be credited with having taken a prominent part in the advancement of terrestrial magnetism and other geophysical subjects. It was owing to his kindly interest and stimulating appreciation that the writer of this biographical sketch was given the means and the opportunity, under the auspices of the Maryland Geological Survey, to carry out a detailed magnetic survey of Maryland (1896-1899).

The example set by Professor Clark was soon followed by the State Geologist of North Carolina, and in 1899, the time appearing ripe to the Superintendent of the United States Coast and Geodetic Survey (then Dr. H. S. Pritchett) for the reorganization of a magnetic survey of the United States along the general lines of the Maryland magnetic survey, the writer was invited to draw up a plan and take charge of such a survey. The experience gained in the latter work led the writer some years later to propose a plan to the Trustees of the Carnegie Institution of Washington for a general magnetic survey of the Earth, which plan, as is well known, has been in actual execution since 1904. Thus the magnetic survey of Maryland may be considered as having been virtually the forerunner of the reorganized magnetic survey of the United States and of the general magnetic survey of the Earth.

Professor Clark's interest led furthermore, in 1899, to the establishment at the Johns Hopkins University of a lectureship in terrestrial magnetism, as also to the offer of the Johns Hopkins Press to act as publisher of *Terrestrial Magnetism and Atmospheric Electricity*. It is not possible for the writer to exaggerate the extent of his obligations to Professor Clark for encouragement, stimulus, and counsel.

William Bullock Clark was born at Brattleboro, Vermont, December 15, 1860; he died suddenly from apoplexy on July 27, 1917, at his summer home, North Haven, Maine. He graduated from Amherst College with the degree of A. B. in 1884, his *alma mater* conferring the honorary degree of LL. D. upon him in 1904. From 1884 to 1887, he pursued geological studies at the University of Munich, where he received the degree of Ph. D. in 1887. He was connected with the geological department of the Johns Hopkins University from 1887 to the year of his death, having been since 1894 head professor of geology and director of the geological laboratory. In 1892, he organized the Maryland State Weather Service, and became its director. The Maryland Geological Survey was organized by him in 1896, Professor Clark serving as State Geologist continuously ever since.

Professor Clark's signal ability was universally recognized. He was honored by leading academies and societies at home and abroad. Probably his greatest monument will be the admirable series of publications issued by the Maryland Geological Survey while he was in charge.

L. A. Bauer.

RECENT PUBLICATIONS

A. Terrestrial and Cosmical Magnetism.

Agincourt and Meanook Observatories. Magnetic observations. February, March, April, 1917. Toronto, J. R. Astr. Soc. Can., v. 11, No. 5, May-June, 1917 (186-187), and No. 6, July-August, 1917 (249-251).

Belot, E. Courbe décrite par le pôle magnétique dans la région boréale depuis 1541. Paris, Bul. soc. astr. France, 31e année, juin 1917 (216-217).

Bouchard, J. Magnétisme terrestre; aurore boréale. Paris, Bul. soc. astr. France, 31e année, février 1917 (51-52).

Copenhagen. Det Danske Meteorologiske Institut. Magnetisk aarbog. Annuaire magnétique. 1915. Kjøbenhavn, G. E. C. Gad, 1917 (11 avec 21 pls.). 32 cm.

Hellmann, G. Bericht über die Tätigkeit des Königlich Preussischen Meteorologischen Instituts im Jahre 1915. Erstattet vom Direktor. Mit einem Anhang enthaltend wissenschaftliche Mitteilungen. Berlin, Veröff. met. Inst., Nr. 290, 1916 [42+(108) mit 1 Tafel.] 27 cm. [Contains Das Meteorologisch-Magnetische Observatorium bei Potsdam (22-29).]

Hongkong, Royal Observatory. Report of the Director of the Royal Observatory, Hongkong, for the year 1916 (T. F. Claxton, Director). Hongkong, Noronha & Co., Govt. Printers, 1917, 14 pp. 24 cm.

Klotz, O. The scientific work of the Government. (Paper read before the Ninth Meeting of the National Assembly of Civil Service Commissions.) Ottawa, J. de L. Taché, 1917. 11 pp. 23 cm.

Klotz, O. Magnetic results, 1916. (In Canada.) Toronto, J. R. Astr. Soc. Can., v. 11, No. 6, July-August, 1917 (208-212).

Mauritius. Results of magnetical, meteorological and seismological observations for the months of October, November, December, 1916, January and February, 1917. New series (monthly), v. 2, Pts. 10, 11, and 12, v. 3, Pts. 1 and 2. Royal Alfred Observatory, Mauritius. (A. Walter, Director.) Mauritius, Govt. Press, 1916, 1917. 32 cm.

Nippoldt, A. Ergebnisse der Messungen in den Jahren 1913 und 1915 an Säkularstationen der magnetischen Landesaufnahme. (Im Anhang zum Bericht über die Tätigkeit des Königlich Preussischen Meteorologischen Instituts im Jahre 1915.) Berlin, Veröff. met. Inst., Nr. 290, 1916 [(32)-(47)].

Ottawa, Department of the Interior. Annual report of the Topographical Surveys Branch, 1915-1916. Ottawa, Dept. of Int., Sessional Paper No. 25b, 1917 (223 with one pocket of 2 maps). 25 cm. [Appendix No. 72 contains results of magnetic observations.]

Schmidt, Ad. Vorläufige Mitteilung über die Ergebnisse der magnetischen Beobachtungen in Potsdam und Seddin im Jahre 1915. (Im Anhang zum Bericht über die Tätigkeit des Königlich Preussischen Meteorologischen Instituts im Jahre 1915.) Berlin, Veröff. met. Inst., Nr. 290, 1916 [(27)-(32)].

Terrestrial Magnetism
and
Atmospheric Electricity

VOLUME XXII DECEMBER, 1917 NUMBER 4

ON THE MAGNETIC AND ELECTRIC FIELDS WHICH SPONTANEOUSLY ARISE IN A ROTATING CONDUCTING SPHERE.

BY W. F. G. SWANN.

INTRODUCTION.

There are several ways in which small magnetic and electric fields may be conceived as arising in a rotating conducting body. Thus, centrifugal force will make the free electrons move away from the axis of rotation, until the electrostatic forces brought about as a result of this phenomenon restore equilibrium. The rotation of a body, a sphere for example, may accordingly, from this cause alone, be expected to result in the generation of magnetic and electric fields. Again, in so far as gravity pulls the electrons, they will tend to move towards the center of the sphere and will do so until the electrostatic forces, etc., resulting from this action restore equilibrium. This effect also provides a reason for the existence of a magnetic field. Analogous remarks result from a consideration of the potential-gradient which arises in a sphere, from causes of the nature of the Thomson effect, when the sphere is hot at the center and cold at the surface.

A very little consideration of the order of magnitude of effects such as those cited above will show, without exact mathematical analysis, that they can play no appreciable part in the explanation of the Earth's magnetism; but it is perhaps nevertheless not without interest, as a problem in pure physics, to calculate the expressions for the fields arising in this way.

The primary influences which we shall consider are those cited above, viz.:

(1) Effects of centrifugal force on the electrons;
(2) Effects of gravity on the electrons; and
(3) Effects of temperature-gradient in the sphere.

It is by no means implied that these are the only agencies which may be invoked to account for the existence of a magnetic field in a rotating sphere; and the only reason for concentrating attention on these influences in particular is that they are of a type for which a calculation of the effects may be made without the introduction of much of a speculative nature. The problem will first be discussed for a case where the specific inductive capacity of the sphere is unity, and the solutions will afterwards be extended to correspond to an arbitrary specific inductive capacity.

The law to be obeyed by the free charge arising in the sphere as a result of the above influences is that expressed by Poisson's equation, which, in spherical polar coordinates and in electromagnetic units takes, for this case, the form

$$\frac{\partial}{\partial r}\left(r^2\frac{\partial V}{\partial \theta}\right) + \frac{1}{\sin\theta}\frac{\partial}{\partial\theta}\left(\sin\theta\frac{\partial V}{\partial\theta}\right) = -4\pi r^2 c^2 \rho \quad ,$$

c being the velocity of light, ρ the charge density, V the potential, and r and θ the polar coordinates of a point. In addition to this, the potential must vary throughout the sphere in such a way that the electrostatic force on a free electron at any point in the sphere just balances the forces represented by the phenomena (1), (2), and (3).

Now the force on an electron as represented by (1) is independent of the distribution of charge in the sphere. A similar remark applies to the force represented by (2) except in so far as the movement of electrons from one place to another alters the resulting distribution of material density in the sphere, a consideration absolutely negligible, however, for the case in hand. Similar conclusions apply to the force represented by (3), and consequently, if we obtain three different solutions corresponding respectively to the cases where the electrostatic forces are such as to balance (1) and (2) and (3) separately, the algebraic sum of these solutions will represent the solution of the problem when (1), (2), and (3) are all considered together. It will be remembered in this connection that the sum of any number of solutions of Poisson's equation for given density distributions is itself a solution for a case where the densities are superposed.

In view of the above remarks, it will be convenient to record the solutions for each of the cases (1), (2) and (3) separately, and in order that the reader need not go through the mathematical analysis unless he should feel so disposed, the results will be given

first, in Section I, the detailed analysis pertaining thereto in Section II, and the extension of the results to the case of an arbitrary specific inductive capacity, in Section III.

Section I.—Results of Mathematical Analysis.

C. G. S. electromagnetic units are employed throughout, and the following notation is used:

e and m, the electronic charge and mass, respectively ($e/m = 1.77 \times 10^7$ E.M.U.);

ω, the angular velocity of the sphere of radius a;

Ω, the magnetic potential at a point outside the sphere;

V, the electrostatic potential;

H, the horizontal, and Z the vertical component of the magnetic field intensity. (In the formulæ, H and Z are measured in the directions of increasing θ and r, respectively; increase of θ corresponds to decrease of northerly latitude, and the direction of rotation of the sphere is from west to east);

Z_p, and H_e, the values of Z at the pole, and H at the equator, respectively;

α, the universal constant defined by the condition that αT is the kinetic energy of a gas molecule at a temperature T;

T_c, and T_s, the temperatures, respectively, of the center and surface of the sphere;

n, the number of free electrons per c.c., a quantity which, following the usual treatment of thermoelectric phenomena, we shall suppose to be related to the temperature by a formula of the type $n = n_0 T^p$, where p varies with the special form of theory of thermoelectric phenomena adopted, and will here be taken as $\frac{3}{2}$[1];

D, the density of the material of the sphere; and

G, the constant of gravitation. Strictly speaking, we are not justified in assuming that the ratio of the mass to weight for an electron is the same as for ordinary matter. Thus, if gravity does not pull the electrons, the effective value of G is zero. In the calculations made in this paper, the ordinary gravitational constant $G = 6.66 \times 10^{-8}$ C.G.S. units is employed.

It will be convenient to collect in Table 1 the main results of the calculations made in the latter portion of the paper, and for purposes of numerical illustration the values of H_e and Z_p are cal-

[1] O. W. Richardson, The Electron Theory of Contact Electromotive Force and Thermoelectricity, *Phil. Mag.*, S. 6, v. 23., p. 276 (1912).

culated for a sphere of radius 20 cm., and density 8.9 (the density of copper), rotating 100 times per second, and for a sphere of the radius (6.4×10^8 cm.), mean density (5.5), and angular velocity of the Earth.

The magnetic potentials have only been calculated for points outside the sphere, although it is, of course, quite easy to write down the potentials inside the sphere when they are known outside.

The quantity I in the last column denotes the value of $\int_{T_s}^{T_c} R^3 dT$, where R is the distance from the center to a point in the sphere. I thus depends upon the relation between the temperature and the distance from the center of the sphere. Its greatest value occurs for a case where the whole of the temperature-fall takes place in a shell near the surface, and in this case the value amounts to $a^3 (T_c - T_s)$. The values of H_e and Z_p have been calculated for this case, and for $T_c - T_s = 5000°$ absolute. It will be noted that the values so calculated are independent of the size of the sphere.

When the rotation is from west to east, the magnetic field due to the gravitational effect is of a nature unlike that of the Earth, and corresponds to the existence of a north-seeking pole at the north pole of the sphere. The field due to the Thomson effect is of a nature similar to that of the Earth for the same direction of rotation.

The field resulting from the centrifugal-force effect is interesting in that the horizontal intensity shows a reversal of sign as one travels over the surface of the sphere. It is zero for the values of θ derived from the equation:

$$\frac{1}{5} - \frac{3}{14} (5 \cos^2 \theta - 1) = 0$$

i. e., for $\theta = 51°.5$ and $128°.5$, which correspond to latitudes 38°.5 north and south, respectively. For latitudes less than 38°.5, the horizontal intensity is in a direction opposite to that corresponding to the gravitational effect, or in the same direction as that of the Earth. The reversal is, of course, attributable to the portion of the charge which is non-uniformly distributed. The vertical intensity is also peculiar in showing a reversal in sign, not only at the equator, but also at parallels 69°.8, north and south.

The magnetic fields given in Table 1 are those which would be measured by an observer at rest with respect to the rotating

TABLE 1.[2]—*Magnetic fields supposing observer at rest with respect to rotating sphere.*

Case	Centrifugal force alone considered	Gravity alone considered	Thermal effects (Thomson effect) alone considered
Nature of charge distribution	Positive volume charge of uniform density, and equal negative surface charge of non-uniform density	Positive volume charge and equal negative surface charge, both of uniform density	Positive volume charge with density a function of distance from center, the form of the function depending on the conditions; the negative surface charge is uniformly distributed and its total amount is equal to that of the volume charge
Ω	Formula (23)	Formula (26)	Formula (29)
H	Formula (23*A*)	Formula (26*A*)	Formula (29*A*)
Z	Formula (23*B*)	Formula (26*B*)	Formula (29*B*)
H_e	Formula (23*C*)	Formula (26*C*)	Formula (29*C*)
Z_p	Formula (23*D*)	Formula (26*D*)	Formula (29*D*)
H_e small sphere[3]	-2.6×10^{-18} E.M.U.	$+5.2 \times 10^{-30}$ E.M.U.	-4.9×10^{-11} E.M.U.
Z_p small sphere	$+1.1 \times 10^{-18}$ E.M.U.	$+1.0 \times 10^{-29}$ E.M.U.	-9.8×10^{-11} E.M.U.
H_e for Earth	-4.1×10^{-24} E.M.U.	$+3.8 \times 10^{-22}$ E.M.U.	-5.7×10^{-18} E.M.U.
Z_p for Earth	$+1.7 \times 10^{-24}$ E.M.U.	$+7.3 \times 10^{-22}$ E.M.U.	-1.1×10^{-17} E.M.U.

sphere. The only part which would be affected if the observer were on the sphere is that corresponding to the centrifugal-force effect, for it alone gives rise to an external electrostatic field; this is so since the volume and surface charges corresponding to the other effects are not only equal and opposite, but are distributed in a manner which involves only the distance from the center of the sphere, and not the angular coordinates.

Following the line of argument indicated by Schuster[4], and independently by the author,[5] if Y is the vertical component and X the horizontal component of the electric field at the surface of the sphere, the values of H_1 and Z_1 at the surface of the sphere, as measured by a moving observer, are connected with the values H and Z as measured by a fixed observer through the relations:

[2] When an arbitrary specific inductive capacity K is assigned to the sphere, all of the results in this table become multiplied by $3/(K + 2)$, as shown in Section III.

[3] Radius $a = 20$ cm.; angular velocity $\omega = 2\pi \times 100$.

[4] A critical examination of the possible causes of terrestrial magnetism; *Proc. Phys. Soc., London*, vol. 24, p. 132, 1912.

[5] "The Earth's magnetic field;" *Phil. Mag.*, sec. 6, vol. 24, p. 91, 1912.

$$H_1 = H - \frac{Y \omega a \sin \theta}{c^2} \tag{1}$$

$$Z_1 = Z + \frac{X \omega a \sin \theta}{c^2} \tag{2}$$

where the rotation is supposed to take place from west to east.

The external electrostatic potential for the case where centrifugal force is taken into account as shown on page 162, is equation 24,

$$V = \frac{m\,\omega^2\,a^5}{3\,er^3}\,(1 - \tfrac{3}{2}\sin^2\theta)$$

Hence $Y - = \frac{\partial V}{\partial r} = \frac{m\,\omega^2\,a}{e}\,(1 - \tfrac{3}{2}\sin^2\theta)$ on the surface of the sphere;

and $X = -\frac{1}{r}\left(\frac{\partial V}{\partial \theta}\right) = \frac{m\,\omega^2\,a}{e}\sin\theta\cos\theta$ " " " .

Hence from the values of H and Z given in table (1), we have, using (1) and (2),

$$H_1 = \frac{3\,m\,\omega^3\,a^2}{7\,c^2\,e}\,(\tfrac{1}{5} - \cos^2\theta)\sin\theta$$

$$Z_1 = \frac{3\,m\,\omega^3\,a^2}{7\,c^2\,e}\,(\tfrac{2}{5} - \sin^2\theta)\cos\theta$$

The facts with regard to the directions of the magnetic fields are summarized in Table 2. In each case, the component H or Z is classified according as its direction is, or is not, the same as that of the Earth, for the same direction of rotation.

Table 2.—*Comparison of types of field obtained with that of the Earth.*

Influence	Observer fixed in space		Observer moving with sphere	
	H	Z	H_1	Z_1
Centrifugal force	Like Earth, lat. 0° to 38°.5 (N. and S).	Like Earth, lat. 0° to 69°.8 (N. and S).	Unlike Earth, lat. 0° to 26°.6 (N. and S).	Like Earth, lat 0° to 50°.8 (N. and S).
	Unlike Earth for latitudes greater than 38°.5 (N. and S).	Unlike Earth for latitudes greater than 69°.8 (N. and S).	Like Earth for latitudes greater than 26°.6 (N. and S).	Unlike Earth for latitudes greater than 50°.8 (N. and S).
Gravitational force	Unlike Earth	Unlike Earth	Unlike Earth	Unlike Earth
Thomson effect	Like Earth	Like Earth	Like Earth	Like Earth

It is of interest to observe that the latitudes at which reversals of the fields take place are independent of all the physical constants, w, a, m, e, c, etc.

Of course, all the fields are extremely small, as may be seen from Table 1, and a consideration of the nature of the quantities upon which they depend shows that neither in the laboratory, where large angular velocities may be produced, nor in the solar or stellar systems, where large dimensions are met with, could these fields amount to an order of magnitude sufficiently great to be measurable by laboratory apparatus. Similar remarks apply to the electrostatic field.

THE ELECTROSTATIC FIELD.

As already remarked, the only influence responsible for an external electrostatic field is the centrifugal-force effect, and the potential V arising in this way, as shown on page 162, is equation 24,

$$V = \frac{m\,\omega^2\,a^5}{3\,e\,r^3}\,(1 - \tfrac{3}{2}\sin^2\theta)$$

The maximum electrostatic potential-gradient occurs at the poles, and it is there equal to $m\omega^2 a/e$. Dividing this by 10^8 to convert it to volts per cm., we find, on inserting numerical values, that the potential-gradient here amounts to 4.5×10^{-9} volts per cm. for the case of a sphere of 20 cm. radius rotating 100 times per second. For the case of a sphere of the size and angular velocity of the Earth, it amounts to 2×10^{-15} volt per cm. The field at the poles is directed upwards from the surface; it is interesting to notice, however, that except at the equator and poles the horizontal component of the potential-gradient attains a finite value.

The internal potential-gradients are of course, in the case of each problem, such that when multiplied by e they give the mechanical force to be balanced.

Thus, as far as the centrifugal-force effect is concerned, the internal potential-gradient is perpendicular to the axis of rotation, and, on the surface, at the equator, it is equal to $m\omega^2 a/(e \times 10^8)$ volts per cm., i. e., 4.5×10^{-9} volts per cm. in the case of the smaller and 2×10^{-15} volts per cm. in that of the larger sphere. It is directed outwards from the axis.

For the case where gravity alone is considered, the internal potential-gradient at the surface is $4\pi GDma/(3\ e \times 10^8)$ volts per cm. This amounts to about 2.8×10^{-20} volts per cm. for the smaller, and 5.5×10^{-13} volts per cm. for the larger sphere. The force is in such a direction as to draw positive electricity towards the center of the sphere.

In the case of the Thomson effect, the maximum internal potential-gradient, for a given difference in temperature between center and surface is determined by the way in which the temperature is distributed. On the free electron theory of thermo-electric phenomena, if P is the pressure of the electrons, the equilibrium of a volume element comprised within the radii R and $R + dR$ and within the solid angle $d\phi$ requires that

$$R^2 n e \frac{\partial V}{\partial R} d R d \phi = \frac{\partial}{\partial R} (R^2 P) d R d \phi - P \frac{\partial R^2}{\partial R} d R d \phi \cdot$$

where n is the number of electrons per c.c. The first term on the right-hand side of the above equation represents the resultant of the hydrostatic pressure on the spherical surface of the volume element, and the second term represents the component force which arises parallel to dR, as a result of the pressure on the remaining surface of the volume element. Since $P = 2\alpha nT/3$, the above equation becomes

$$\frac{\partial V}{\partial R} = \frac{2\alpha}{3en} \frac{d(nT)}{dR} \tag{3}$$

For a case where n varies as $T^{\frac{3}{2}}$, this gives

$$\frac{\partial V}{\partial R} = \frac{5\alpha}{3e} \frac{dT}{dR}$$

For a case where $\frac{dT}{dR}$ is constant

$$\frac{\partial V}{\partial R} = - \frac{5\alpha(T_c - T_s)}{3ea} = -2 \times 10^4 \frac{(T_c - T_s)}{a}$$

or $-2 \times 10^{-4} \frac{(T_c - T_s)}{a}$ Volts per cm.

Thus the field amounts to only 2×10^{-4} volts per cm. per gradient of 1° C. per cm. The field is, of course radial, and is in a direction such as to drive positive electricity outwards from the center.

Section II.—Mathematical Analysis Pertaining to Section I.

We shall first quote one or two well-known results which we shall have occasion to use.

Let there be a circular ring carrying a current u, the ring being of such a size that its diameter subtends an angle 2β at the center of a sphere of radius a. Then, the magnetic potential Ω at a point outside the sphere is given by[6]

$$\Omega = 2\pi u \sin^2 \beta \sum_{n=1}^{\infty} \left(\frac{1}{n+1} \right) \frac{a^{n+1}}{r^{n+1}} P_n'(\beta) P_n(\theta) \tag{4}$$

where, if μ is written for $\cos \beta$, $P_n'(\beta) = \dfrac{d P_n(\mu)}{d \mu}$

and the P^s refer to the ordinary Legendre coefficients.

If M units of electric charge are distributed uniformly on the above ring, the electrostatic potential V due to this charge is, at a point outside the sphere of radius a,

$$V = \frac{M c^2}{r} \sum_{n=0}^{\infty} \frac{a^n}{r^n} P_n(\beta) P_n(\theta) \tag{5}$$

and, at a point inside the sphere,

$$V = \frac{M c^2}{a} \sum_{n=0}^{\infty} \frac{r^n}{a^n} P_n(\beta) P_n(\theta) \tag{6}$$

The magnetic potential due to a sphere of radius a rotating with angular velocity ω, and charged to a surface density s is, at a point outside the sphere[7],

$$\Omega = \frac{4\pi \omega s a^4}{3 r^2} \cos \theta = \frac{E \omega a^2}{3 r^2} \cos \theta \tag{7}$$

where E is the total charge on the sphere.

Problem 1.—Determination of Ω, when centrifugal force alone is considered.

The charge distribution within the rotating sphere must satisfy Poisson's equation, which for the present case is

$$\frac{\partial}{\partial r}\left(r^2 \frac{\partial V}{\partial r} \right) + \frac{1}{\sin \theta} \frac{\partial}{\partial \theta}\left(\sin \theta \frac{\partial V}{\partial \theta} \right) = -4\pi \rho c^2 r^2 \tag{8}$$

[6] See Maxwell, *Treatise on Electricity and Magnetism*, second edition, vol. 2, p. 333.

[7] See, for example, W. Sutherland, *Terr. Mag.*, v. 5, p. 74, 1900.

Since the electrical force on an electron must balance the centrifugal force, we have

$$- e \frac{\partial V}{\partial r} = m\,\omega^2\,r\,\sin^2\theta, \quad - \frac{e}{r}\left(\frac{\partial V}{\partial \theta}\right) = m\,\omega^2\,r\,\sin\theta\cos\theta \qquad (9)$$

where it is to be understood that in the above formulæ, *as in all formulæ in this paper*, a positive number is to be inserted for e, although the electron itself is, of course, negatively charged.

From (9) we readily find that V must be given by,

$$V = - \frac{m\,\omega^2\,r^2}{2\,e} \sin^2\theta + V_0 \qquad (10)$$

where V_0 is a constant. On substituting in (8) the value of V given by (10), we obtain,

$$\rho = \frac{m\,\omega^2}{2\,\pi\,c^2\,e} \qquad (11)$$

The charge density is thus constant throughout the sphere, and is, of course, positive.

The distribution ρ, as given by (11), will not by itself produce the value of V given by (10); indeed, it corresponds only to a part U given by

$$U = \frac{4\,\pi\,a^3\,\rho\,c^2}{3\,a} + \tfrac{4}{3}\,\pi\,\rho\,c^2 \int_r^a \frac{r^3}{r^2}\,d\,r$$

$$= \frac{m\,\omega^2}{3e}\,(3\,a^2 - r^2 \qquad (12)$$

where it will be observed that the first and second members on the right-hand side of (12) represent, respectively, the parts of U corresponding to the paths from infinity to the surface of the sphere, and from the surface to the distance r from the center. We have

$$V - U = \frac{m\,\omega^2\,r^2}{3\,e}\,(1 - \tfrac{3}{2}\sin^2\theta) - \frac{m\,\omega^2\,a^2}{e} + V_0 \qquad (13)$$

The part of V represented by V-U is accounted for by the appearance, on the surface of the sphere, of a negative charge, which is the complement of the positive distribution ρ. V-U must, of course, be a solution of (8) with ρ zero, i. e., of La Place's equation; and that it is so may easily be verified. The total amount of negative charge on the surface of the sphere is, of course,

$$Q_s = -\tfrac{4}{3}\pi a^3 \rho = -\frac{2\, m\, \omega^2 a^3}{3\, c^2 e} \tag{14}$$

The distribution of negative charge on the surface of the sphere may be looked upon as made up of two parts, a part distributed with variable surface density σ in such a way as to produce the term $\frac{m\,\omega^2 r^2}{3\,e}(1 - \frac{3}{2}\sin^2\theta)$ in the expression for V-U, and a part uniformly distributed, which accounts for the contribution $-\frac{m\,\omega^2 a^2}{e} + V_0$ in (13). The fact that the total surface charge has to be equal to the value given by (14) is, of course, the determining factor in fixing V_0.

Now using (6) with M replaced by $2\pi a^2 \sin\beta\, d\beta$ to correspond to the range β to $\beta + d\beta$, and remembering that $1 - \frac{3}{2}\sin^2\theta = P_2(\theta)$, we see that σ must be such that

$$\frac{m\,\omega^2 r^2}{3\,e} P_2(\theta) = 2\pi a c^2 \int_0^{\pi} \sigma \sin\beta \sum_{n=0}^{\infty} \frac{r^n}{a^n} P_n(\beta)\, P_n(\theta)\, d\beta$$

$$= 2\pi a c^2 \sum_{n=0}^{\infty} \frac{r^n}{a^n} P_n(\theta) \int_{-1}^{+1} \sigma\, P_n(\mu)\, d\mu \tag{15}$$

If this equation is to hold, the integral must be zero for all values of n except $n = 2$, and this restricts σ to be proportional to $P_2(\mu)$. Writing $\sigma = k\, P_2(\mu)$, k readily becomes determined from (15), and we find

$$\sigma = \frac{5\, m\, \omega^2 a}{12\,\pi\, c^2 e} P_2(\mu) \tag{16}$$

Since, as may readily be verified, the integration of $P_2(\mu)$ over the surface of the sphere leads to a zero result, we see that σ contributes nothing to the total charge on the surface, so that the uniformly distributed portion must account for the whole of the value of Q_s given by (14), and so must be equal, but, of course, opposite in sign, to the total volume charge.

Thus, as far as the effect of centrifugal force is concerned, equilibrium is attained by the appearance of[8]

(A) A volume charge of constant density $\rho = \dfrac{m\,\omega^2}{2\,\pi\,c^2\,e}$;

(B) A surface charge of uniform density and total amount $-\dfrac{2\,m\,\omega^2\,a^3}{3\,c^2\,e}$ plus a surface charge of density $\sigma = \dfrac{5\,m\,\omega^2\,a}{12\,\pi\,c^2\,e}\,P_2(\mu)$, and consequently of total amount zero.

Using (7), we find for the magnetic potential $d\Omega_1$ due to the rotation of the portion of the volume charge comprised between the radii R and $R + dR$

$$d\,\Omega_1 = \frac{4\,\pi\,\omega\,\rho\,R^4}{3\,r^2}\cos\theta\,d\,R \tag{17}$$

Hence, the potential Ω_1 due to the whole volume distribution, is

$$\Omega_1 = \frac{4\,\pi\,\rho\,\omega\,a^5}{15\,r^2}\cos\theta$$

or in terms of the total volume charge Q

$$\Omega_1 = \frac{Q\,\omega\,a^2}{5\,r^2}\cos\theta \tag{18}$$

Substituting the value of Q as determined above, we have

$$\Omega_1 = \frac{2\,m\,\omega^3\,a^5}{15\,c^2\,e\,r^2}\cos\theta \tag{19}$$

The potential Ω_2 due to the portion of the surface charge which is uniformly distributed and of total amount $-\,2\,m\,\omega^2\,a^3/3c^2e$ is, using (7)

$$\Omega_2 = -\,\frac{2\,m\,\omega^3\,a^5}{9\,c^2\,e\,r^2}\cos\theta \tag{20}$$

In order to obtain the potential Ω_3 due to the portion σ of the surface distribution, we must use (4), replacing u by $\omega a^2 \sigma \sin\beta\,d\beta$, and integrating from $\beta = 0$ to π. Thus, using (16)

$$\Omega_3 = \frac{5\,m\,\omega^3\,a^3}{6\,c^2\,e}\sum_{n=1}^{\infty}\left(\frac{1}{n+1}\right)\frac{a^{n+1}}{r^{n+1}}\int_0^{\pi} P_2(\beta)\,P_n{}'(\beta)\sin^3\beta\,d\,\beta \tag{21}$$

[8] It may be remarked that, although an electron in the body of the sphere would be in equilibrium under the above forces, the surface charge *itself* would not be in equilibrium under these forces alone. This does not affect our calculations, however; for a little consideration will show that the force which, as far as the above influences are concerned, is unbalanced, is directed along the outwardly drawn normal to the surface, and it becomes balanced by the attraction which the matter exerts in preventing the electricity from leaving the sphere. The point is, in fact, exactly analogous to that met with in the case of a stationary and uniformly charged conducting sphere, where, although the force inside the sphere, due to the surface charge, is zero, there is nevertheless a force on the surface charge itself of amount $2\pi\,\sigma^2$ per unit of area.

On making use of the relations

$$\int_{-1}^{+1} Pm\,(\mu)\; Pn\,(\mu)\; d\,\mu = 0 \text{ for } n \neq m$$

$$= \frac{2}{2\,n+1} \text{ for } n = m$$

it may readily be shown that the integral in (21) is zero except for $n = 1$ and $n = 3$, in which cases it amounts to $-\ 4/15$ and $+\ 24/35$, respectively. Hence, on substituting the values,

$$P_1\,(\theta) = \cos\theta \text{ and } P_3\,(\theta) = \tfrac{1}{2}\,(5\cos^3\theta - 3\cos\theta)$$

in (21), we readily obtain

$$\Omega_3 = -\,\frac{m\,\omega^3\,a^3}{3\,c^2\,e}\left\{\frac{a^2}{3\,r^2}\cos\theta - \frac{3\,a^4}{14\,r^4}\,(5\cos^3\theta - 3\cos\theta)\right\} \tag{22}$$

Hence, from (19), (20), and (22), we obtain for the total magnetic potential:

$$\Omega = -\,\frac{m\,\omega^3\,a^3}{c^2\,e}\left\{\frac{a^2}{5\,r^2}\cos\theta - \frac{a^4}{14\,r^4}\,(5\cos^3\theta - 3\cos\theta)\right\} \tag{23}$$

The corresponding horizontal and vertical components (H and Z) of the field are:

$$H = -\,\frac{m\,\omega^3\,a^3}{c^2\,e}\left\{\frac{a^2}{5\,r^3} - \frac{3\,a^4}{14\,r^5}\,(5\cos^2\theta - 1)\right\}\sin\theta \tag{23A}$$

$$Z = -\,\frac{m\,\omega^3\,a^3}{c^2 e}\left\{\frac{2\,a^2}{5\,r^3} - \frac{2\,a^4}{7\,r^5}\,(5\cos^2\theta - 3)\right\}\cos\theta \tag{23B}$$

The value of H at the equator, and on the surface, and the value of Z at the pole, and on the surface are respectively:

$$H_e = -\,\frac{29\,m\,\omega^3\,a^2}{70\,c^2\,e} \tag{23C}$$

$$Z_p = \frac{6\,m\,\omega^3\,a^2}{35\,c^2\,e} \tag{23D}$$

PROBLEM 2.—DETERMINATION OF THE EXTERNAL ELECTROSTATIC POTENTIAL WHEN CENTRIFUGAL FORCE ALONE IS CONSIDERED.

The external potential arises entirely from the non-uniformly distributed portion of the surface charge represented by σ, since the uniformly distributed part is just equal in total amount to the uniformly distributed volume charge. In order to obtain the external potential V arising from the distribution σ, we use (5), replacing M by $2\pi a^2 \sigma \sin\beta\, d\beta$, and integrate from $\beta = 0$ to π. Thus, using (16)

$$V = \frac{5 m \omega^2 a^3}{6 e r} \sum_{n=0}^{\infty} \frac{a^n}{r^n} P_n(\theta) \int_0^{\pi} \sin\beta\, \mathrm{P}_2(\beta)\, \mathrm{P}_n(\beta)\, d\beta$$

Putting $\cos\beta = \mu$, we see that the integral becomes

$$\int_{-1}^{+1} P_2(\mu)\, P_n(\mu)\, d\mu,$$

which is zero, unless $n = 2$, in which case it is $2/5$. Hence remembering that $P_2(\theta) = 1 - 3/2 \sin^2\theta$, we have

$$V = \frac{m \omega^2 a^5}{3 e r^3} \left(1 - \tfrac{3}{2} \sin^2\theta\right) \tag{24}$$

PROBLEM 3.—DETERMINATION OF Ω, WHEN GRAVITY ALONE IS CONSIDERED.

Using the notation defined on page 151, and subject to the restriction there cited with regard to G, the gravitational force on an electron at a distance R from the center of the sphere is $4\pi R D G m/3$. It is thus possible to balance this force by a uniform distribution of negative charge throughout the sphere, the density ρ_0 of the charge being given by,

$$\tfrac{4}{3}\pi R D G m = -\tfrac{4}{3}\pi R \rho_0 C^2 e$$

Thus

$$\rho_0 = -\frac{D G m}{c^2 e}$$

The total negative volume-charge corresponding to this distribution is

$$Q_0 = -\frac{4\pi D a^3 G m}{3 c^2 e} \tag{25}$$

and the condition for neutrality of the sphere as a whole is satisfied by placing an equal positive charge on the surface. If this charge is uniformly distributed, it will produce no force inside the sphere, and so will not alter the conclusions recorded above with regard to the equilibrium of the gravitational and electrical forces.[9]

From (18) we see that the magnetic potential arising from the charge Q_0 is

$$\bar{\Omega}_1 = -\frac{4\pi D G m \omega a^5}{15 c^2 e r^2} \cos\theta$$

and from (7) the magnetic potential arising from the surface charge is

$$\bar{\Omega}_2 = \frac{4\pi D G m \omega a^5}{9 c^2 e r^2} \cos\theta$$

and the resultant potential is

$$\bar{\Omega} = \frac{8\pi D G m \omega a^5}{45 c^2 e r^2} \cos\theta \tag{26}$$

Of course, the volume and surface charges together give rise to no electrostatic potential at a point outside the sphere.

The corresponding values of H, Z, H_e, and Z_p are:

$$\bar{H} = \frac{8\pi D G m \omega a^5}{45 c^2 e r^3} \sin\theta \tag{26A}$$

$$\bar{Z} = \frac{16\pi D G m \omega a^5}{45 c^2 e r^3} \cos\theta \tag{26B}$$

$$\bar{H}_e = \frac{8\pi D G m \omega a^2}{45 c^2 e} \tag{26C}$$

$$\bar{Z}_p = \frac{16\pi D G m \omega a}{45 c^2 e} \tag{26D}$$

PROBLEM 4.—DETERMINATION OF Ω WHEN EFFECTS OF THE NATURE OF THE "THOMSON EFFECT" ALONE ARE CONSIDERED.

As shown on page 156, the equilibrium of the electrons in the volume element $R^2 dR d\psi$ requires that the potential-gradient shall satisfy the equation (3). Since $\frac{\partial V}{\partial R}$ is independent of the

[9] See footnote 8, page 160.

angular coordinates, it will be provided for if, within the radius R, there is a charge Q_R given by $\frac{c^2 Q_R}{R^2} = -\frac{\partial V}{\partial R}$. Thus, using (3),

$$Q_R = -\frac{2\alpha R^2}{3c^2 e n} \frac{d(nT)}{dR} \tag{27}$$

The total surface-charge will, of course, be equal and opposite to the volume charge, so that since both are *symmetrically* distributed with respect to the center (although the volume charge is not *uniformly* distributed), there will be no external electric field.

Since the charge contained within the shell $4\pi R^2 dR$ is $\frac{dQ}{dR}$ the magnetic potential $d\overline{\overline{\Omega}}_1$, resulting from the rotation of this shell is, using (7):

$$d\overline{\overline{\Omega}}_1 = \frac{\omega R^2}{3r^2} \frac{dQ_R}{dR} \cos\theta \, dR$$

and the magnetic potential due to the rotation of the whole volume charge is, after integrating by parts:

$$\overline{\overline{\Omega}}_1 = \frac{\omega a^2 Q_a}{3r^2} \cos\theta - \frac{2\omega\cos\theta}{3r^2} \int_0^a R\, Q_R\, dR \tag{28}$$

where Q_a is the total volume charge.

Again, using (7), the magnetic potential due to the surface charge $-Q_a$ is seen to be equal in magnitude but opposite in sign to the first term of (28), so that we have for the total potential $\overline{\overline{\Omega}}$ resulting from volume and surface charges,

$$\overline{\overline{\Omega}} = -\frac{2\omega\cos\theta}{3r^2} \int_0^a R\, Q_R\, dR$$

Using (27), we obtain, after changing the variable from R to T,

$$\overline{\overline{\Omega}} = -\frac{4\alpha\omega\cos\theta}{9c^2 e r^2} \int_{T_s}^{T_c} \frac{R^3}{n} \frac{d(nT)}{dT} dT$$

where T_c and T_s are respectively the temperatures of the center and surface of the sphere. We cannot proceed further without assigning some manner in which T is to vary with R, and assuming a relation between n and the temperature. If, following certain considerations resulting from the free electron theory of thermo-

electric phenomena, [10] we assume n proportional to T^p, where p is a constant which varies somewhat with the form of theory adopted, we obtain,

$$\overline{\overline{\Omega}} = -\frac{4(p+1)\,a\,\omega\cos\theta}{9c^2 e r^2}\int_{T_s}^{T_c} R^3\,dT \qquad (29)$$

Writing I for the integral, the coresponding values of H, Z, H_e, and H_p are:

$$\overline{\overline{H}} = -\frac{4(p+1)\,a\,\omega}{9c\cdot e r^3} I \sin\theta \qquad (29\,A)$$

$$\overline{\overline{Z}} = -\frac{8(p+1)\,a\,\omega}{9c^2 e r^3} I \cos\theta \qquad (29\,B)$$

$$\overline{\overline{H}}_e = -\frac{4(p+1)\,a\,\omega}{9c^2 e a^3} I \qquad (29\,C)$$

$$\overline{\overline{Z}}_p = -\frac{8(p+1)\,a\,\omega}{9c^2 e a^3} I \qquad (29\,D)$$

SECTION III.—EXTENSION OF THE RESULTS TO THE CASE WHERE THE SPECIFIC INDUCTIVE CAPACITY IS NOT UNITY.

Let K be the specific inductive capacity of the sphere. The actual force on an electron in the body of the sphere is now no longer the force derivable from the free volume and surface charges. If E is the electric intensity in the dielectric, and P the polarization (moment per unit volume), the force on unit charge is

$$F = E + 4\pi\gamma P$$

where γ is a constant, less than unity, depending on the nature of the medium. For isotropic bodies we may take γ as roughly $\frac{1}{3}$,[11] so that since $KE = E + 4\pi P$, we have

$$F = E + \frac{(K-1)\,E}{3} = \frac{(K+2)\,E}{3}$$

Hence, in order to balance the mechanical forces, it is now necessary that the value of E at each point on the sphere shall be $3/(K + 2)$ times the value appropriate for the case $K = 1$ already discussed. Poisson's equation for the present case becomes

$$\frac{\partial}{\partial r}\left(r^2\frac{\partial V}{\partial r}\right) + \frac{1}{\sin\theta}\frac{\partial}{\partial\theta}\left(\sin\theta\frac{\partial V}{\partial \theta}\right) = -\frac{4\pi r^2 c^2 \rho_0}{K}$$

[10] See O. W. RICHARDSON, The electron theory of contact electromotive force and thermoelectricity. *Phil. Mag.*, ser. 6, vol. 23, p. 276, 1912.

[11] See H. A. LORENTZ, *Theory of Electrons*, p. 139.

where ρ_0 is the true volume density at a point in the sphere. Hence, since, at each point of the sphere, V/r and V/θ must now have values equal to $3/(K + 2)$ times the values for $K = 1$, we see that if ρ is the volume density for $K = 1$, Poisson's equation will be satisfied for any value of K by taking

$$\frac{\rho_0}{K} = \frac{3\rho}{K+2}$$

Now according to the well-known theory of dielectric action, the portion of a dielectric medium enclosed within a boundary S acts, as regards the potential at external points, or at points in a hole within the boundary, as though it comprised a volume charge of density $-\left(\frac{\partial P_x}{\partial x} + \frac{\partial P_y}{\partial y} + \frac{\partial P_z}{\partial z}\right)$ at each point of its volume, and a surface charge of surface density Pn at each point of its surface, including the surface of the hole, if there be one. Pn is here the component of P in the direction of the outwardly drawn normal. At a point within the dielectric, E is defined as the field obtained in a small cavity surrounding the point, after subtracting the part contributed by the "fictitious" charge on the surface of the cavity.

If ρ_1 refers to the fictitious volume density, we have

$$\rho_1 = -\left(\frac{\partial P_x}{\partial x} + \frac{\partial P_y}{\partial y} + \frac{\partial P_z}{\partial z}\right) = -\frac{(K-1)}{4\pi K}\left(\frac{\partial B_x}{\partial x} + \frac{\partial B_y}{\partial y} + \frac{\partial B_z}{\partial z}\right)$$

where B_x, B_y, B_z are the components of the electric induction.

$$\text{But,} \quad \frac{\partial B_x}{\partial x} + \frac{\partial B_y}{\partial y} + \frac{\partial B_z}{\partial z} = 4\pi\rho_0$$

$$\text{Hence,} \quad \rho_1 = \frac{(1-K)}{K}\rho_0$$

$$\text{and,} \quad \rho_1 + \rho_0 = \frac{\rho_0}{K} = \frac{3\rho}{(K+2)} \tag{29}$$

Hence, if σ refers to the surface density for the case $K = 1$, and if σ_0 and σ_1 refer respectively to the true and "fictitious" surface densities for the present value of K, we readily see that by writing

$$\sigma_1 + \sigma_0 = \frac{3\sigma}{(K+2)} \tag{30}$$

the value of $\sigma_1 + \sigma_0$ so assigned will be just of the right type to provide for the necessary forces not provided for by the volume

charge. In fact, calling the sum of the true and fictitious charge densities the "virtual" charge density, we shall now have a virtual volume charge density of amount $3\rho/(K + 2)$, and a virtual surface charge density of amount $3\sigma/(K + 2)$, and these will provide for fields $3/(K + 2)$ times those provided for by the distributions ρ and σ in the case $K = 1$, which is just what is required.

Further, our choice of $\sigma_1 + \sigma_0$ as given by (30) provides for the compensation of total volume and surface charges. For the equality of the volume integral of ρ and the negative of the surface integral of σ has been provided for in the problems for the case $K = 1$, and equations (29) and (30) show that this equality extends to the volume integral of $\rho_1 + \rho_0$ and the negative of the surface integral of $\sigma_1 + \sigma_0$. Again, the volume integral of ρ_1 is equal to the negative of the surface integral of σ_1, since

$$\iiint \left(\frac{\partial P_x}{\partial x} + \frac{\partial P_y}{\partial y} + \frac{\partial P_z}{\partial z} \right) dx\,dy\,dz = \iint P_n\,dS$$

Hence, the volume integral of ρ_0 is equal to the negative of the surface integral of σ_0[12].

We have thus seen that the virtual volume and surface distribution are $3/(K + 2)$ times those found for the case $K = 1$. Hence, the external and internal electric fields are $3/(K + 2)$ times those found for the case $K = 1$.

The magnetic field is produced partly by the motion of the true charges and partly by the motion of the polarized dielectric. It is not immediately obvious that the latter part is accounted for by the rotation of the fictitious charges, but that it is so accounted for may be seen from the following analysis:

The magnetic field may be expressed as the curl of the vector-potential corresponding to the motion of all the electricity in the system. If r is the distance from a moving charge of strength e, to a point O, the vector-potential at O, in any direction specified by the subscript h, and due to the moving charge is, to a first approximation, $\frac{eV_h}{r}$, where the vector V_h is the component velocity of the charge parallel to the assigned direction. If now in company with the charge e there moves another charge $-e$, at a small distance l from it, the combined contribution to the vector-potential

[12] Although $\sigma^1 + \sigma_0$ is proportional to σ, it is interesting to note that, in general, for example in the case of the problem where centrifugal force is considered, σ_0 is not proportional to σ, although ρ_1 is always proportional to ρ. The dielectric alters the types of distribution of the true surface charges, but compensates for such alteration in type by means of the fictitious charge.

is $\frac{le\,d}{ds}\left(\frac{V_h}{r}\right)$, where the differentiation is performed in the direction of the length of the doublet, from the negative to the positive charge.

$$\text{Now } l\,e\frac{\partial}{\partial s}\left(\frac{V_h}{r}\right) = l\,e\left\{\frac{\partial}{\partial x}\left(\frac{V_h}{r}\right)\frac{\partial x}{\partial s} + \frac{\partial}{\partial y}\left(\frac{V_h}{r}\right)\frac{\partial y}{\partial s} + \frac{\partial}{\partial z}\left(\frac{V_h}{r}\right)\frac{\partial z}{\partial s}\right\}$$

$$= \mu_x\frac{\partial}{\partial x}\left(\frac{V_h}{r}\right) + \mu_y\frac{\partial}{\partial y}\left(\frac{V_h}{r}\right) + \mu_z\frac{\partial}{\partial z}\left(\frac{V_h}{r}\right) \qquad (31)$$

where μ_x, μ_y, μ_z, are the components of polarization of the doublet. The contribution to the vector-potential by unit volume of the polarized medium is obtained by replacing μ_x, μ_y, μ_z, by P_x, P_y, P_z, and the total values of the vector-potential in the direction specified by h, and resulting from the whole dielectric inclosed within the surface S is

$$\iiint\left\{P_x\frac{\partial}{\partial x}\left(\frac{V_h}{r}\right) + P_y\frac{\partial}{\partial y}\left(\frac{V_h}{r}\right) + P_z\frac{\partial}{\partial z}\left(\frac{V_h}{r}\right)\right\}dx\,dy\,dz$$

$$= -\iiint\frac{V_h}{r}\left(\frac{\partial P_x}{\partial x} + \frac{\partial P_y}{\partial y} + \frac{\partial P_z}{\partial z}\right)dx\,dy\,dz + \iint\left(\frac{P_n V_h}{r}\right)ds$$

But this is just the contribution which would be supplied by the fictitious volume and surface charges. Hence, the rotation of the sphere is represented as regards its magnetic and electrical effects by the rotation of the true and fictitious volume and surface charges, and therefore, the magnetic and electric forces may be obtained for any value of K, from the corresponding results for $K = 1$, by simply multiplying those results by $3/(K + 2)$.

The modifications introduced when the observing instruments participate in the motion of the sphere may be carried out in a manner exactly analogous to that adopted on pages 153, 154.

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LATEST ANNUAL VALUES OF THE MAGNETIC ELEMENTS AT OBSERVATORIES.[1]

COMPILED BY J. A. FLEMING.

Observatory	Latitude	Longitude	Year	Declination (D)	Inclination (I)	Intensity (Hor. H)	Intensity (Ver. Z)
	° ′	° ′		° ′	° ′	c.g.s.	c.g.s.
Sitka[2]	57 03 N	135 20 W	1913	30 22.0 E	74 27.7 N	.15606	.56128
			1914	30 22.9 E	74 26.6 N	.15605	.56055
			1915	30 23.2 E	74 26.5 N	.15593	.56008
			1916	30 24.0 E	74 26.0 N	.15580	.55917
Rude Skov	55 51 N	12 27 E	1914	8 53.6 W	68 48.2 N	.17293	.44592
			1915	8 44.3 W	68 50.6 N	.17257	.44591
Kasan	55 47 N	49 08 E	1909	8 05.1 E	69 09.1 N	.18118	.47575
			1910	8 03.3 E	69 09.7 N	.18098	.47547
			1911	8 04.5 E	69 15.1 N	.18052	.47652
			1912	8 09.1 E	69 17.3 N	.18017	.47651
Eskdalemuir	55 19 N	3 12 W	1913	17 54.9 W	69 37.3 N[3]	.16822	.45282[3]
Stonyhurst	53 51 N	2 28 W	1915	16 38.0 W[4]	68 41.4 N	.17342[4]	.44457
Potsdam	52 23 N	13 04 E	1914	8 26.6 W	66 22.9 N	.18760	.42901[5]
			1915	8 17.1 W	66 25.1 N	.18726	.42899
			1916	8 07.6 W	66 27.1 N	.18698	.42904
Seddin	52 17 N	13 01 E	1914	8 28.1 W[6]	66 19.9 N	.18798	.42887[6]
			1915	8 18.4 W	66 22.1 N	.18764	.42884
			1916	8 08.9 W	66 24.1 N	.18736	.42889
De Bilt	52 06 N	5 11 E	1913	12 32.1 W	66 45.9 N[7]	.18525[7]	.43151
			1914	12 22.6 W	66 46.5 N	.18512	.43140
Valencia[8]	51 56 N	10 15 W	1913	20 19.6 W	68 09.2 N	.17892	.44628
Kew	51 28 N	0 19 W	1913	15 37.0 W	66 55.8 N	.18505	.43449
			1914	15 27.8 W	66 55.8 N	.18488	.43406
			1915	15 18.4 W	66 56.6 N	.18463	.43376
Greenwich	51 28 N	0 00	1915	14 56.5 W	66 51.8 N[9]	.18508	.43315[10]
			1916	14 46.9 W	66 52.8 N[9]	.18494	.43317[10]

[1] From compilations by Dr. Charles Chree in British Meteorological and Magnetic Year Book for 1913, part IV, section 2, with additions by J. A. Fleming, Department of Terrestrial Magnetism, Carnegie Institution of Washington. See tables for previous years in *Terr. Mag.*, vol. 4, p. 135; vol. 5, p. 128; vol. 8, p. 7; vol. 12, p. 175; vol. 16, p. 209; and vol. 20, p. 131. Referring to the last reference, the latitude of Ekaterinburg should read 56° 50′N, instead of 57° 03′N; also the vertical intensities of Barrackpore for 1911 and 1912 should read .22220 and .22316 instead of .21220 and .21316.

[2] Standard in H changed at end of 1912; new standard in H from 1913 is $0.001H$ less than that used through 1912 (see p. 9, Results of Observations, etc., at Sitka, Alaska, 1913 and 1914—U. S. Coast and Geodetic Survey). The values for 1916 are preliminary.

[3] Values from first 5 and last 5 months of the year.

[4] From magnetograph for 10 quietest days in each month.

[5] Corrected value.

[6] Corrected values.

[7] Corrected values.

[8] Two absolute observations per month.

[9] Earth-inductor observations.

[10] Computed from I and H.

Observatory	Latitude	Longitude	Year	Declination (D)	Inclination (I)	Intensity	
						(Hor. H	Ver. (Z)
	° ′	° ′		° ′	° ′	c.g.s.	c.g.s.
Cracow....	50 04 N	19 58 E	1913	5 03.3W	64 18.4 N	....	....
Val Joyeux.	48 49 N	2 01 E	1913	13 59.2W	64 38.9 N	.19744	.41673
Munich ...	48 09 N	11 37 E	1911	9 23.8W	63 06.2 N	.20633	.40676
Pola......	44 52 N	13 51 E	1914	7 48.3W	60 03.5 N	.22190	.38524
			1915	7 39.0W	60 05.1 N	.22166	.38526
Agincourt (Toronto)	43 47 N	79 16 W	1914	6 23.8W	74 41.4 N	.16086	.58761[11]
			1915	6 28.5W	74 42.9 N	.16028	.58644
			1916	6 33.4W	74 43.5 N	.15987	.58538
Tiflis......	41 43 N	44 48 E	1908	2 39.8 E	56 28.4 N	.25404	.37343
			1909	2 46.8 E	56 32.1 N	.25377	.37391
			1910	2 52.7 E	56 35.5 N	.25343	.37422
			1911	2 57.4 E	56 41.2 N	.25289	.37480
			1912	3 03.1 E	56 46.0 N	.25255	.37545
			1913	3 09.1 E	56 51.1 N	.25217	.37612
Ebro (Tortosa)	40 49 N	0 31 E	1914	12 51.6W	57 47.5 N	.23295	.36981
Coimbra...	40 12 N	8 25W	1913	16 12.1W	58 38.6 N	.23046	.37820
			1914	16 04.7W	58 36.4 N	.23057	.37782
			1915	15 57.5W	58 34.7 N	.23053	.37734
Cheltenham[12]...	38 44 N	76 50 W	1913	5 54.6W	70 41.1 N	.19599	.55917
			1914	5 59.8W	70 44.0 N	.19510	.55815
			1915	6 04.0W	70 46.8 N	.19417	.55694
			1916	6 07.6W	70 49.9 N	.19335	.55621
Tokio.....	35 41 N	139 45 E	1912	5 03.4W	48 53.7 N[13]	.29996	.34379
Tucson[14]...	32 15 N	110 50 W	1913	13 37.0 E	59 21.8 N	.27247	.46006
			1914	13 39.9 E	59 23.1 N	.27188	.45946
			1915	13 42.5 E	59 24.7 N	.27119	.45879
			1916	13 44.4 E	59 26.1 N	.27063	.45824
Lukiapang.	31 19 N	121 02 E	1909	2 59.6W	45 34.9 N	.33226	.33906
Dehra Dun....	30 19 N	78 03 E	1913	2 22.2 E	44 16.4 N	.33191	.32359
			1914	2 18.8 E	44 22.9 N	.33165	.32458
Barrackpore[14a] ..	22 46 N	88 22 E	1913	0 38.0 E	30 54.8 N	.37388	.22387
			1914	0 32.2 E	30 58.9 N	.37403	.22459

[11] Computed from *I* and *H*.

[12] Standard in *H* changed at end of 1912; new standard in *H* from 1913 is 0.001*H* less than that used through 1912 (see p. 4, Results of Observations, etc., at Cheltenham, 1913 and 1914—U. S. Coast and Geodetic Survey). The values for 1916 are preliminary.

[13] Computed from *Z* and *H*.

[14] Standard in *H* changed at end of 1912; new standard in *H* from 1913 is 0.001*H* less than that used through 1912 (see p. 10, Results of Observations, etc., at Tucson, 1913 and 1914—U. S. Coast and Geodetic Survey).

[14a] Observations were discontinued April 26, 1915.

Observatory	Latitude	Longitude	Year	Declination (D)	Inclination (I)	Intensity Hor. (H)	Intensity Ver. (Z)
	° ′	° ′		° ′	° ′	c.g.s.	c.g.s.
Hongkong	22 18 N	114 10 E	1912	0 04.5W[15]	30 56.3 N	.37193[16]	.22294
			1913	0 06.5W[15]	30 53.7 N	.37172[16]	.22242
			1914	0 08.8W[15]	30 53.5 N	.37192[16]	.22251
			1915	0 11.7W	30 52.2 N	.37167[16]	.22217
			1916	0 13.8W	30 51.8 N	.37155[16]	.22205
Honolulu[17]	21 19 N	158 04 W	1913	9 37.3 E	39 32.6 N[18]	.29075	.24005
			1914	9 39.6 E	39 30.4 N	.29045	.23949
			1915	9 41.6 E	39 29.1 N	.29005	.23897
			1916	9 43.8 E	39 29.2 N	.28957	.23859
Toungoo	18 56 N	96 27 E	1913	0 07.8 E	23 05.0 N	.38963	.16605
			1914	0 02.6 E	23 06.1 N	.38983	.16628
Alibag	18 38 N	72 52 E	1915	0 40.6 E	24 21.1 N[19]	.36870	.16688[19]
Vieques[20]	18 09 N	65 26 W	1913	2 49.6W	50 21.2 N	.28522	.34421
			1914	3 00.4W	50 33.9 N	.28401	.34533
			1915	3 10.1W	50 45.9 N	.28279	.34630
			1916	3 19.4W	50 56.7 N	.28154	.34700
Kodaikanal	10 14 N	77 28 E	1913	1 11.2W	4 05.5 N	.37553	.02686
			1914	1 17.1W	4 11.2 N	.37571	.02750
Batavia-Buitenzorg	6 11 S	106 49 E	1912	0 47.3 E	31 19.4 S	.36683	.22324
Samoa (Apia)	13 48 S	171 46 W	1905	9 37.0 E	(29 11.8S)[21]	.35675[21]	(.19935)
			1906	9 38.5 E	29 15.7 S[21]	.35655	.19977
			1907	9 40.1 E	29 18.9 S[21]	.35637	.20010
			1908	9 41.9 E	29 21.8 S[21]	.35613	.20036
			1909[22]	9 43.9 E	....	.35590	....
			1910[22]	9 45.7 E	....	.35550	....
			1911[22]	9 47.4 E	29 36.1 S	.35527	.20183
			1912[22]	9 50.3 E	29 41.2 S	.35487	.20230
			1913[22]	9 51.9 E	29 45.9 S	.35455	.20277
			1914[22]	9 53.7 E	29 49.5 S	.35429	.20313
			1915[22]	9 56.8 E	29 52.7 S	.35389	.20332
			1916[22]	9 59.9 E	29 54.5 S	.35364	.20343

[15] Corrected values.

[16] Based on $P = 7.05$ instead of year's mean as before.

[17] Standard in H changed at end of 1912; new standard in H from 1913 is $0.001H$ less than that used through 1912 (see p. 8, Results of Observations, etc., at Honolulu, 1913 and 1914—U. S. Coast and Geodetic Survey). The values for 1916 are preliminary.

[18] Change of earth inductors in 1913; the results by the instrument used prior to 1913 appear 3′.0 too high.

[19] Schulze inductor.

[20] Standard in H changed at end of 1912; new standard in H from 1913 is $0.001H$ less than that used through 1912 (see p. 10, Results of Observations, etc., at Vieques, 1913 and 1914—U. S. Coast and Geodetic Survey). The values for 1916 are preliminary.

[21] Corrected values.

[22] Preliminary values.

Observatory	Latitude	Longitude	Year	Declination (D)	Inclination (I)	Intensity	
						Hor. (H)	Ver. (Z)
	° ′	° ′		° ′	° ′	c.g.s.	c.g.s.
Mauritius..	20 06 S	57 33 E	1914	9 34.7 W	53 07.6 S[23]	.23256	.31004
			1915	9 41.1 W	53 00.2 S[23]	.23226	.30833
Pilar......	31 40 S	63 53 W	1914	8 40.4 E	25 41.5 S	.25597	.12315
Christchurch...	43 32 S	172 37 E	1914	16 44.8 E	67 59.8 S	.22413	.55465
New Year's Island...	54 45 S[24]	64 03 W[24]	1902	15 57.3 E	50 13.8 S[25]	.27306	.32808
			1903	15 53.7 E	50 12.0 S[25]	.27280	.32742
			1904	15 49.6 E	50 09.6 S[25]	.27226	.32631
			1905	15 45.7 E	50 06.6 S[25]	.27196	.32536
			1906	15 41.6 E	50 03.6 S[25]	.27167	.32443

[23] This value is as determined by the earth inductor mounted on western pier of the magnetic pavilion and reduced to eastern pier, the one used for previous dip-circle work; "Dip on the western pillar is 2.′9 smaller than on the eastern."

[24] Provisional values, taken for position given for Port Cork, p. 298 of the American Practical Navigator, 1914 edition.

[25] Computed from *H* and *Z*.

THE RADIUM CONTENT OF SEA-SALT SPECIMENS COLLECTED ON CRUISE IV OF THE *CARNEGIE*.

BY C. W. HEWLETT.

The following is an account of an investigation which was carried out in the laboratory of the Department of Terrestrial Magnetism at Washington to determine the amount of radium in some samples of sea salt collected by the *Carnegie* in the Atlantic and Pacific oceans, 1915-1917.[1] The method of investigation was that first used by Joly and described by him in volume 32 of the *Philosophical Magazine*, 1911. The sea salt was mixed with two to three times its weight of a fusion mixture of sodium and potassium carbonates, and this mixture was heated to about 1,000° C. in an electric furnace. At this temperature carbon dioxide bubbled off from the mixture and presumably carried with it any radium emanation previously present in the mixture. The gases from the furnace were then introduced into the ionization chamber associated with an electroscope, and investigated for radioactivity.

Description of Apparatus.—The electrical furnace was tubular, about 1.5 inches internal diameter and the heated length about 12 inches. The fusion mixture was made of equal molecular weights of the anhydrous carbonates of sodium and potassium. A steel tube, 17 inches long and 1.5 inches external diameter, was inserted in the electric furnace. The ends of this tube were closed with perforated rubber stoppers. One rubber carried a tube which conducted the furnace-gases away for investigation, while the other held a short glass tube about 1 cm. in diameter. This tube extended about 1.5 inches outside the stopper and its end was closed with a flat piece of glass, so that a view could be had inside the furnace. Into the side of this tube another tube of smaller diameter was joined, and a piece of rubber tubing controlled by a pinch cock was attached to this smaller tube. By means of this arrangement air could be admitted to the furnace for washing it out after all the carbon dioxide had been driven off. The end

[1] The investigation here described was carried out under the immediate direction of Dr. W. F. G. Swann.

portions of the steel tube were kept cool by dripping water on them. A collar of cotton was wound around each end and water, dripping from two siphons into a large vessel supported above the apparatus, fell on these collars. This then dripped into two funnels and was carried off to the waste. The rubber stoppers were protected from radiation from the furnace by perforated brass plugs placed between the stoppers and the furnace.

The gases leaving the furnace first passed into a flask containing soda lime, where chlorine, carbon dioxide, and water vapor were partially absorbed. They next passed into a rubber bladder, where they collected until the heating was completed. These gases were then sucked into a glass flask containing silver and copper shavings, the connections being made in such a way that the gases in passing from the rubber bag to the flask, passed back through the flask of soda lime. The gases were then allowed to remain in the flask containing the metal shavings for 10 minutes, so that any remaining gases harmful to the insulation inside the ionization chamber might be used up. The gases in the flask were then admitted to the previously exhausted ionization chamber. It was usually necessary to fill the ionization chamber twice in order to secure a thorough wash-out of the furnace. The volume of the steel tube was about 300 cc., of the unoccupied portion of the soda-lime flask, about 100 cc., of the flask containing the metal shavings, about 500 cc., and of the ionization chamber about 1,200 cc. The volume of the connecting tubes was negligible.

A nickle boat whose volume was about 30 cc. was used to contain the melt of sea salt and fusion mixture. Further, this nickle boat was contained in a nickle shield to protect the iron tube in case the melt boiled over. The samples of sea salt to be investigated were sealed up in thin walled glass tubes for periods of time varying from 3 to 13 days, so even if the salt had no emanation when sealed up, it should have had, when tested, from 0.4 to 0.9 of its equilibrium value.

The electroscope used was a Wulf single quartz fiber instrument adjusted to a sensibility of 20 divisions per volt. The ionization chamber was charged to 100 volts above the case of the electroscope, and the method used for measuring the ionization current was that used on the *Carnegie* for measuring the ionization current in determinations of the radioactivity of the atmosphere.

Experimental Procedure.—From 5 to 12 grams of sea salt were

mixed with from 2 to 3 times its weight of the fusion mixture and heated in the furnace. The furnace was brought up to its highest temperature slowly, and the total time of heating was about 2 hours. As soon as the rubber bag had collected a sufficient amount of gas, the ionization chamber was filled, allowing the gases, however, to reside in the flask containing the metal shavings for 10 minutes on their way to the chamber.

These gases were then tested for radioactivity while more gas was collecting in the rubber bag. After these gases had been satisfactorily investigated, they were sucked out of the ionization chamber, the rest of the gases were admitted, and the furnace was washed out. The pressure in the ionization chamber was always adjusted to atmospheric pressure before observations were made. The ionization chamber contained a dish of phosphorus pentoxide for drying the gases. This was found to have quite a good effect on the insulation.

A word might be said in regard to the procedure on board the *Carnegie* in collecting the sea salt. When the date of collection is given over several days, as in the first item in the table at the end of this paper, from 1 to 1.5 liters of sea water were collected in equal amounts on all the days from the first to the last given, inclusive. When a single date is given, the sea water was taken only on that date. The water was then put in a copper vessel and evaporated to dryness. The residue in the copper vessel was then scraped out, closed up in a test tube, and forwarded to the laboratory in Washington.

Upon undertaking the present investigation it was found that the samples of sea salt were damp. Each sample was evaporated to dryness in a porcelain evaporation dish, and was then ground up in a mortar. A portion of each sample was sealed up in a thin-walled glass receptacle for the present investigation, the rest of each sample being carefully sealed up in a test tube for future work. These thin-walled glass tubes were sealed with bits of paraffin wax, so that they would open up in the furnace without explosion.

Results.—Upon admitting the gases to the ionization chamber, quite a large saturation current was observed, but this current decreased rapidly with the time and usually by the end of one hour it had disappeared. This initial effect was very troublesome till the flask containing the metal shavings was introduced into

the path of the gases. It is suspected that this effect is due to very large ions brought over from the furnace. This initial effect being variable in its magnitude, it was impossible to allow for it in the calculations, so that it was necessary to observe with each set of gases in the chamber for nearly an hour, or even longer, to be sure that all the heavy ions had been removed by the field.

Fifteen samples of sea salt were investigated for radium emanation, but in none of these samples was any emanation found. Various other observers have found values ranging around 10^{-12} curie of radium emanation per gram of sea salt, but the samples in these cases have usually been collected much nearer to land than the bulk of those on the *Carnegie*. The average amount of salt used in a determination was about 8 grams, so that if the radium content were as high as that found by former observers 8×10^{-12} curie of emanation was to be expected. Experiments with known amounts of radium emanation showed that 8×10^{-12} curie of emanation should cause a drift of the electroscope fiber of from 0.5 to 1.5 divisions per minute. A drift of 0.05 division per minute could be detected, so that it would seem that the sea salt tested in these experiments contained not more than 10% of the radium emanation which has been found by other observers.

Experiments with known amounts of radioactive material were made in various ways: By putting a fairly large amount of the unsealed material together with some fusion mixture into the furnace and heating it; by sealing a certain amount of radioactive material for a definite time and then putting this in the furnace with some fusion mixture; and finally by placing with a usual charge of sea salt and fusion mixture a small amount of radioactive material, containing a small amount of emanation of the order of magnitude of that expected from the sea salt. Some of this same sample of sea salt had been previously tested for emanation, and it was found to have none. This test with the radioactive material was made to eliminate the possibility that such a small amount of emanation might be prohibited from coming off by the large amount of material with which it was mixed.

As examples of the method of observation the two determinations, with the sea salt and carbonates alone, and then with a sample of the same sea salt, carbonates, and radioactive material, will suffice.

EXAMPLE 1.

Date: Aug. 28, 1917. 9.61 grams of sea salt sealed up at 11^h 27^m a. m., Aug. 25, 1917, mixed with 17 grams of fusion mixture. This mixture was placed in the furnace and direct current turned on as follows:

	h m	First Gases Admitted to: Flask (metal shavings) h m	Chamber h m
42 volts at	2 18 p. m.		
72 " "	2 32		
96 " "	2 46		
120 " "	3 14	3 36 p. m.	3 53 p. m.
96 " "	3 47	3 54	4 04
0 " "	4 18	4 05	4 15

Preliminary Drift of Electroscope-Reading.

Reading	Time h	m	s	Time for 2-division drift m	s
51	3	21	20 p. m.		
50		22	47	2	25
49		23	45		
51	3	24	10		
50		25	20	2	30
49		26	40		
51	3	27	00		
50		28	10	2	15
49		29	15		
			Mean	2	23

Drift of Electroscope-Reading with First Gases in the Ionization-Chamber.

Reading	Time h	m	s	Time for 2-division drift m	s	Reading	Time h	m	s	Time for 2-division drift m	s
51	4	19	20 p. m.			51	4	41	00 p. m.		
50		20	20	1	50	50		42	30	2	45
49		21	10			49		43	45		
51	4	21	30			51	4	44	10		
50		22	40	2	05	50		45	25	2	30
49		23	35			49		46	40		
51	4	23	50			51	4	47	00		
50		24	55	2	00	50		48	20	2	50
49		25	50			49		49	50		
			Mean	1	58				Mean	2	42

Second Gases Admitted to:

Flask (metal shavings) h	m	Chamber h	m
4	15 p. m.	4	54 p. m.
4	55	5	05

Drift of Electroscope-Reading with Second Gases in the Ionization-Chamber.

Reading	Time h	m	s	Time for 2-division drift m	s
51	5	14	30 p. m., Aug. 28		
50		14	45	0	35
49		15	05		
51	5	15	20		
50		15	35	0	35
49		15	55		
51	5	16	15		
50		16	35	0	40
49		16	55		
			Mean	0	37
51	9	51	10 a. m., Aug. 29		
50		52	10	2	15
49		53	25		
51	9	53	50		
50		55	00	2	34
49		56	24		
51	9	56	45		
50		58	18	2	35
49		59	20		
51	9	59	40		
50	10	01	00	2	35
49		02	15		
			Mean	2	30

Reading	Time h	m	s	Time for 2-division drift m	s
51	10	12	35 a. m., Aug. 29		
50		13	55	2	20
49		14	55		
51	10	15	18		
50		15	20	2	30
49		17	48		
51	10	18	05		
50		19	08	2	10
49		20	15		
51	10	20	35		
50		22	00	2	37
49		23	12		
			Mean	2	24

Second Gases Cleared Out of Ionization-Chamber, and Drift Again Observed.

Reading	Time h	m	s	Time for 2-division drift m	s
51	10	36	45 a. m.		
50		37	40	2	00
49		38	45		
51	10	39	10		
50		40	40	2	55
49		42	05		

Reading	Time h	m	s	Time for 2-division drift m	s
51	10	42	20 a. m.		
50		43	30	2	25
49		44	45		
51	10	45	10		
50		46	05	2	25
49		47	35		
			Mean	2	26

Since the time for a drift of 2 divisions is as long when the gases which were driven off from the sea salt were in the ionization-chamber as when the ordinary room gases were in the ionization-chamber, it follows that the emanation driven off from the amount of the sea salt is smaller than the electroscope would detect.

The following is a record of the test made with a portion of the same sample of sea salt as the above test, but this time a small amount of carnotite containing an amount of radium emanation of the order of magnitude of that looked for in the sea salt, was added.

Example 2.

Date: Aug. 31, 1917. 6.82 grams of sea salt sealed up at $12^h\ 12^m$ p. m., Aug. 30, 1917, contain also a thin tube of carnotite, mass 0.32 milligram sealed up at $11^h\ 05^m$ a. m., Aug. 24. The whole was put into the nickle boat with 18 grams of fusion mixture, and the boat was put into the furnace. The heating took place with the direct current turned on as follows:

			First Gases Admitted to:			
	h	m	Flask (metal shavings) h	m	Chamber h	m
42 volts at	11	26 a. m.				
72 " "	11	36				
96 " "	11	46				
120 " "	00	30 p. m.	00	58 p. m.	1	08 p. m.
96 " "	1	03	1	10	1	20
0 " "	1	32	1	21	1	31

Preliminary Drift of Electroscope-Reading.

Reading	Time h	m	s	Time for 2-division drift m	s
51	12	13	00 p. m.		
50		13	50	2	00
49		15	00		
51	12	15	15		
50		16	15	2	35
49		17	50		
51	12	18	10		
50		19	15	2	20
49		20	30		

Reading	Time h	m	s	Time for 2-division drift m	s
51	12	21	38 p. m.		
50		22	30	1	47
49		23	25		
51	12	24	00		
50		25	10	2	20
49		26	20		
51	12	26	45		
50		27	50	1	55
49		28	40		
			Mean	2	10

Drift of Electroscope-Reading with First Gases in the Ionization-Chamber.

Reading	Time h	m	s	Time for 2-division drift m	s
51	1	51	20 p. m.		
50		51	55	1	02
49		52	22		
51	1	52	45		
50		53	18	1	02
49		53	47		
51	1	54	00		
50		54	23	0	52
49		54	52		
			Mean	0	59

Reading	Time h	m	s	Time for 2-division drift m	s
51	2	34	20 p. m.		
50		34	40	1	23
49		35	43		
51	2	36	00		
50		..	..	1	18
49		37	18		
51	2	37	45		
50		38	35	1	23
49		39	08		
51	2	39	30		
50		40	05	1	18
49		40	48		
51	2	41	10		
50		..	..	1	14
49		42	24		
51	2	42	40		
50		43	20	1	23
49		44	03		
			Mean	1	22

Second Gases Admitted to:

Flask (metal shavings) h	m	Chamber h	m
1	31 p. m.	2	53 p. m.
2	54	3	04
3	05	3	15

Drift of Electroscope-Reading with Second Gases in the Ionization-Chamber.

Reading	Time h	m	s	Time for 2-division drift m	s	Reading	Time h	m	s	Time for 2-division drift m	s
51	3	31	00 p. m.			51	4	16	00 p. m.		
50		31	45	1	40	50		16	55	2	00
49		32	40			49		18	00		
51	3	33	00			51	4	18	20		
50		33	45	1	45	50		19	05	1	30
49		34	45			49		19	50		
51	3	35	00			51	4	20	10		
50		36	00	1	55	50		21	15	2	03
49		36	55			49		22	13		
			Mean	1	47	51	4	22	50		
						50		23	55	2	15
						49		25	05		
						51	4	25	25		
						50		26	18	1	40
						49		27	05		
						51	4	27	20		
						50		28	35	1	55
						49		29	15		
									Mean	1	54

Second Gases Cleared Out of the Ionization-Chamber and Drift Again Observed.

Reading	Time h	m	s	Time for 2-division drift m	s	Reading	Time h	m	s	Time for 2-division drift m	s
51	4	35	30 p. m.			51	4	40	35 p. m.		
50		36	25	2	13	50		41	33	2	00
49		37	43			49		42	35		
51	4	38	10			51	4	43	00		
50		39	10	2	00	50		44	05	2	25
49		40	10			49		45	25		
									Mean	2	10

By the time the final readings with the second gases were taken, most of the activity due to the active deposit from the emanation first admitted had, of course, disappeared. The object of sealing the specimen of carnotite for some days before use, was to make the radium content a more definite quantity. Thus, if a specimen contained no emanation when sealed, it would acquire 0.7 of its equilibrium amount in 7 days.

Computation of these results show that a drift of 0.1 division per minute at the end of one hour corresponded to 1.7×10^{-12} curie of radium emanation in the ionization-chamber. This drift could easily be detected, and 1.7×10^{-12} curie of emanation is of the order of magnitude of the amount to be looked for in one gram of sea salt according to previous investigations.

The following table contains the data in regard to the samples of sea salt investigated:

Date Collected	Lat. °	Long. (E. of Gr.) °	Grams Sea Salt	Grams Fusion Mixture
May 24–30, 1916	35 S	186	10.00	30
Sept. 10–16, 1916	44 N	221	6.87	17
June 27–July 3, 1916	10 N	180	5.31	19
June 20–26, 1916	5 S	188	6.09	18
July 4–11, 1916	18 N	165	7.36	23
Aug. 27–Sept. 9, 1916	49 N	191	6.02	21
Dec. 7–13, 1916	19 S	235	9.04	18
July 12–16, 1916	16 N	150	7.77	20
Aug. 20–26, 1916	44 N	160	7.76	15
Jan. 2– 8, 1917	20 S	248	8.28	17
Jan. 10–16, 1917	16 S	234	9.61	17
Jan. 22–29, 1917	35 S	219	12.31	17
Dec. 27, 1915	59 S	270	7.10	17
Jan. 26, 1916	55 S	20	6.56	17
Dec. 26, 1915	59 S	270	8.18	17

In none of these cases was any radium emanation detected.

In conclusion, mention should be made of Observers H. F. Johnston, I. A. Luke, B. Jones, and A. D. Power, who collected the samples of salt. The author also wishes to express his thanks to Doctors Day and Sosman of the Geophysical Laboratory, for the loan of an alundun-tube heating-element, to Doctor Dorsey, of the Bureau of Standards, for the loan of an analyzed specimen of carnotite, and to the Bureau of Mines for supplying an analyzed specimen of pitchblend.

MAGNETIC OBSERVATIONS AT THE SAMOA OBSERVATORY DURING THE SOLAR ECLIPSE OF AUGUST 21, 1914.

G. Angenheister.

The following table gives the 5-minute values of the magnetic elements during the solar eclipse of August 21, 1914, at the Samoa Observatory (Apia; latitude, 13° 48′ S; longitude, 171° 46′ W). *E. D.* stands for east magnetic declination; *H*, for horizontal intensity, and —*Z*, for negative vertical intensity. The values for 11^h are the means for the interval from $10^h\ 57^m.5$ to $11^h\ 02^m.5$, etc.

G. M. T.		ED	H	—Z	G. M. T.		ED	H	—Z	G. M. T.		ED	H	—Z
h	m	° ′	γ	γ	h	m	° ′	γ	γ	h	m	° ′	γ	γ
10	00	9 53.5	35406	20322	11	45	9 53.3	35410	20323	13	25	9 53.4	35410	20324
	05	3.3	09	4		50	3.3	09	4		30	3.4	10	4
	10	3.2	11	4		55	3.3	09	4		35	3.4	10	4
	15	3.4	12	4	12	00	3.3	08	4		40	3.4	10	4
	20	3.5	11	3		05	3.3	08	4		45	3.4	10	4
	25	3.4	11	2		10	3.3	08	4		50	3.4	10	4
	30	3.4	11	2		15	3.2	07	4		55	3.4	10	4
	35	3.4	12	3		20	3.3	06	4	14	00	3.3	09	4
	40	3.3	13	3		25	3.3	05	3		05	3.4	09	4
	45	3.3	13	4		30	3.4	05	3		10	3.4	08	4
	50	3.3	14	4		35	3.4	05	3		15	3.5	07	4
	55	3.3	13	4		40	3.3	05	4		20	3.5	06	4
11	00	3.4	12	4		45	3.3	06	4		25	3.6	06	4
	05	3.4	11	4		50	3.3	08	4		30	3.7	06	4
	10	3.4	11	3		55	3.4	08	4		35	3.8	06	4
	15	3.5	10	3	13	00	3.4	09	4		40	3.8	06	4
	20	3.4	10	3		05	3.3	09	4		45	3.9	05	4
	25	3.2	10	3		10	3.4	09	4		50	3.9	05	4
	30	3.4	10	3		15	3.4	09	4		55	4.0	05	4
	35	3.4	10	3		20	3.4	09	4	15	00	4.0	05	4
	40	3.3	10	3										

Apia, Samoa, July 7, 1917.

SEA SURFACE-TEMPERATURE AND METEOROLOGICAL OBSERVATIONS MADE ON THE *CARNEGIE* DURING HER SUB-ANTARCTIC CRUISE, DECEMBER 6, 1915, TO APRIL 1, 1916.

By J. P. Ault.

Table 1 contains the results of sea surface-temperature and meteorological observations made on board the *Carnegie* during her sub-Antarctic cruise,[1] December 6, 1915-April 1, 1916, from Lyttelton (New Zealand) to South Georgia and Lyttelton. Reports that have thus far come from this region are few and incomplete, and as the part of the Great Southern Ocean traversed is the scene of such rapid and extreme changes in meteorological conditions, any additional information on the subject may be of interest.

The *Carnegie* made a complete circum-navigation of the globe from west to east, mainly between the parallels of latitude 50° and 60° south, in one season, the summer of 1915-1916, during which Sir Ernest Shackelton's expedition was meeting with such serious reverses. The meteorological observations made by the two parties of his expedition, and those obtained on the *Carnegie*, are especially valuable because they are contemporaneous records of the conditions prevailing in different parts of the southern regions at that time.

The *geographic positions* given in the table are the corrected noon positions, all resulting from good observations. The longitudes have been corrected for an error of 22 seconds in the chronometers at the end of a four-months' cruise.

The various symbols used to describe the *conditions of the weather* show the changes that took place in the weather during the day, given in chronological order: they have the following significance:

b.—Clear blue sky.	h.—Hail.
c.—Cloudy weather.	l.—Lightning.
d.—Drizzling, or light rain.	m.—Misty, or hazy weather.
f.—Fog, or foggy weather.	o.—Overcast.
g.—Gloomy, or dark stormy-looking weather.	p.—Passing showers of rain.
	q.—Squally weather.

[1] For an account of this cruise see *Terr. Mag.*, v. 21, pp. 26, 27, 103-106.

r.—Rainy weather, or continuous rain.
s.—Snow, snowy weather, or snow falling.
t.—Thunder.
u.—Ugly appearance, or threatening weather.
v.—Variable weather.
w.—Wet, or heavy dew.

The true direction from which the wind was blowing and the force are next tabulated, the different directions being the important shifts in the wind during the day, given in chronological order, the day being reckoned from midnight to midnight throughout the table. The Beaufort scale is used in denoting the *force of the wind*, the figures having the following significance:

0.—Calm.
1.—Light air.
2.—Light breeze.
3.—Gentle breeze.
4.—Moderate breeze.
5.—Fresh wind.
6.—Strong wind.
7.—Moderate gale.
8.—Fresh gale.
9.—Strong gale.
10.—Whole gale.
11.—Storm.
12.—Hurricane.

The *barometric pressure* was scaled from the various sheets of an aneroid barograph and corrected by comparisons with readings made daily at Greenwich mean noon on a closed cistern type mercurial barometer. 20 readings were always taken on the mercurial barometer, 10 highs and 10 lows. These readings were reduced to standard, corrected for temperature and reduced to sea level. In the next two columns are tabulated the *amount and duration of change* between a high barometric pressure and the next low barometric pressure, or a low and the next high, as the case may be. The change is considered positive if the mercury is rising or pressure is increasing. Considering these changes in connection with the changes as indicated in the column containing the "true direction of the wind," it will be noticed that almost invariably during the entire 4 months, with a high and decreasing barometric pressure a northerly wind shifted to the west, blowing a gale, then shifted to the southwest as the barometric pressure began to increase and blew hard if the rise was rapid.

A thermograph, placed in the usual type of open-air meteorological shelter-house on deck, kept a continuous record of the *temperature of the air*. Wet and dry bulb thermometers were kept in the same shelter house and were read every four hours during both day and night. The results given in the "*Relative Humidity*" column were taken from "Landolt-Börnstein, Physikalisch-Chem-

ische Tabellen," using the temperature of the dry bulb and the difference between wet and dry bulb.

The *temperature of the sea water* was recorded every hour while at sea, both day and night. A small canvas bucket was used, water was taken from about 2 feet under the surface, and the temperature was read with the thermometer in the water. A plain glass thermometer divided into degrees centigrade and without guard was used. In the next column headed T_a-T_s is given the *difference in centigrade degrees between the air temperature and that of the sea*, the difference being reckoned positive if the air is warmer than the water and negative if it is colder.

The results of *observations for ocean current*, as the continuous rough sea caused the log to overrun, are not very reliable. The velocity column gives the *number of miles per day*. The *true directions of the current* are finally tabulated.

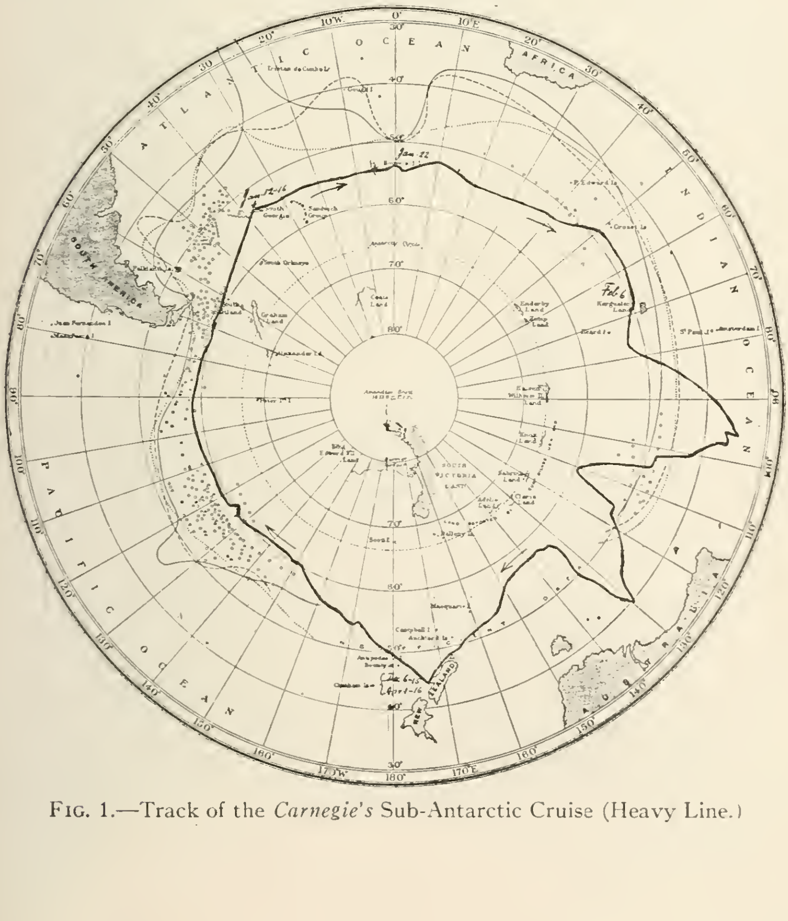

FIG. 1.—Track of the *Carnegie's* Sub-Antarctic Cruise (Heavy Line.)

Table I.—*Sea-Surface Temperature and Meteorological Observations on the Carnegie's Sub-Antarctic Cruise.*

Date 1915-16	Noon Position S. Lat.	Noon Position E. Long.	Weather	Wind Direction* (True)	Force Min.	Force Max.	B. P. 700 mm.+ Min.	B. P. 700 mm.+ Max.	B. P. 700 mm.+ Mean	B. P. Change Am't	B. P. Change Dur.	Rel. Hum.	Air Temp.	Sea Temp.	T_a-T_s	Ocean Current Vel.	Ocean Current Direction
	° ′	° ′					mm	mm	mm	mm	h	%	°	°	°	m/d	°
Dec. 6	Lytt	elton	bcc	NE.E	5	5	.....	65.1	.....	......	......	96	13.4	13.0	+0.4	.....	....
7[1]	46 14	174 44	odc	NE.E-N.E-S.W	2	5	42.3	57.3	49.8	......	......	96	12.5	11.2	+1.3	12	N42W
8	47 47	176 23	odqc	SW.S-SW.W-WSW-SW.S	5	9	39.9	42.3	41.1	—25.2	56	96	9.0	9.9	—0.9	16	N16W
9[2]	49 10	178 41	dqocp	SW.S	4	9	42.3	48.7	45.5	......	......	90	8.8	9.5	—0.7	15	N 3E
9[3]	50 11	181 42	oqpc	SW.S-SW	4	7	48.8	51.8	50.3	+11.9	52	87	7.5	9.4	—1.9	18	N39W
10	51 15	184 01	ocdmr	SW-WNW-NNW-WSW-SSW	2	6	45.9	51.8	48.8	—5.9	19	88	9.0	9.4	—0.4	14	N17W
11	53 16	186 54	mdcqpr	SW S-WSW-WNW-NNW	2	7	42.5	50.9	46.7	+5.0	18	89	9.2	10.1	—0.9	19	N43W
12	53 54	188 53	odc	NNW-W-SSW-S E-SW.S	2	6	39.7	46.3	43.0	—11.2	19	88	6.5	9.0	—2.5	15	N44E
13[4]	54 30	191 44	ocqlr	SW.S-SW-SSW	4	5	46.0	46.8	46.4	......	......	82	6.5	8.5	—2.0	13	N 9W
14	55 18	194 51	cqpoq	SSW-S-SSW-S.W-SSW	2	6	45.8	53.6	49.7	+13.9	64	84	4.4	6.8	—2.4	11	N67W
15	56 00	197 38	obcd	SSW-WNW-N-NNE	1	6	40.8	52.9	46.8	......	......	88	4.1	5.2	—1.1	14	N34W
16	57 10	201 58	odmr	NNE-NNW-WNW	6	10	26.3	40.8	33.6	—27.3	36	99	4.7	3.2	+1.5	24	S29W
17	58 58	205 25	omrd	WNW-NNW-NW-NNW	5	5	22.8	28.3	25.6	+2.0	17	94	2.2	0.5	+1.7	16	N34W
18[5]	60 18	208 50	omds	N.W-NE.N-E.N-S.E	3	5	13.9	22.8	18.4	—14.4	40	98	0.2	—0.2	+0.4	16	N53W
19[6]	60 19	214 18	ms	SSE-S.E-S.W-WNW	5	6	14.3	21.3	17.8	+7.4	27	96	—0.2	—0.2	0.0	18	S79W
20[7]	60 30	220 26	mso	WNW-N.W	4	6	19.7	20.9	20.3	—1.6	6	96	0.1	0.0	+0.1	15	S5 W
21[8]	61 14	226 31	mso	N.W-NNW	5	8	19.7	31.3	25.5	......	......	98	0.8	0.6	+0.2	27	S39W
22[9]	59 40	232 08	obcd	NNW-NNE-N-NNW-NNE	2	5	31.3	40.3	35.8	+20.6	65	94	4.0	2.6	+1.4	22	S22W
23[9]	60 43	236 25	ordmf	NE.N-NE-NNE	3	6	32.8	40.3	36.6	......	......	94	4.6	3.7	+0.9	14	S15E
24[9]	59 59	236 03	fo	NNE-Calm-W.S-WNW-SW	0	7	30.1	35.3	32.7	—10.2	31	94	4.2	4.1	+0.1	13	S85E
25	59 12	242 17	odr	WSW-SW-W.S	6	7	35.3	39.5	37.4	+9.4	35	91	4.2	4.4	—0.2	8	N63W
26	59 07	249 20	ordmbc	WSW-W-N.W	6	6	36.8	38.3	37.6	......	......	93	4.8	4.5	+0.3	23	S68W
27	59 10	256 31	odq	N.W-NNW-NW.W	6	7	22.9	26.7	24.8	—16.6	37	90	5.1	4.8	+0.3	24	S35W
28	58 48	262 52	oqbc	NW.W-W.N-W	5	6	25.9	33.8	29.8	......	......	87	5.4	5.4	0.0	21	S45W
29	58 47	268 30	ordbc	W-WSW-SW.S-Calm	0	5	33.8	42.9	38.4	+20.0	61	89	5.6	5.7	—0.1	12	N89W
30	58 49	271 33	ocdb	W.N-WNW-SSW-S.E-W.S	1	3	40.8	42.7	41.8	......	......	76	5.4	5.9	—0.5	6	S89W
31	58 56	274 15	bcwb	NNW-N.E-N.W	1	4	41.7	42.5	42.1	......	......	85	5.4	6.4	—1.0	10	S53W
Jan. 1	59 17	279 59	bodmp	N-N.E-NNE-N.E	4	6	39.8	42.7	41.2	......	......	87	7.0	6.0	+1.0	13	S71W
2	60 04	285 30	odmfr	NNW-NNE-N	4	5	38.9	39.6	39.2	—4.0	98	96	6.1	5.6	+0.5	17	S5 W
3	59 41	292 00	mrdb	N.E-NNE	3	5	38.9	41.3	40.1	+2.4	10	94	6.2	5.2	+1.0	22	S35W
4	60 09	294 45	mowfd	NNE-NE.E-E-Calm-WNW	0	3	33.3	38.9	36.1	......	......	96	4.4	4.4	0.0	34	S81E
5	59 16	297 18	dobcb	W.N-NW.N-NNW	4	4	33.3	48.9	41.1	—8.0	33	92	5.6	4.0	+1.6	28	N61W
6	58 42	302 25	bodr	NW.N-N.E-NNW-N.E-NW.N	4	9	40.3	50.4	45.4	+17.1	35	94	4.2	3.0	+1.2	17	38E
7	57 44	307 37	omb	NW.N-WNW-W-S	4	9	40.1	.....	.....	—10.3	16	92	4.4	2.5	+1.9	9	S39W
					....	....	.....	51.3	45.7	+11.2	22	....	.....	.....	.....	....	....
8	56 26	312 47	cdobc	WNW-NW.N-Calm	0	5	47.3	51.1	49.2	......	......	94	4.8	3.2	+1.6	14	S21W

[1] Extensive mirage of land appears in direction Banks Peninsula, 190 miles distant. [2] Antipodes lds. bear 210°, 25 miles distant. [3] Crossed 180th meridian of longitude. [4] Heavy southeast swell. [5] Passed first small iceberg. [6] Many large icebergs. Heavy snow squalls. High seas. [7] Icebergs. [8] Icebergs; high seas. [9] Icebergs.
* A period is used for the connecting word "by" in the abbreviations of directions.

Table I.—*Sea-Surface Temperature and Meteorological Observations on the Carnegie's Sub-Antarctic Cruise—Continued.*

Date 1916	Noon Position S. Lat.	Noon Position E. Long.	Weather	Wind Direction* (True)	Force Min.	Force Max.	B. P. 700 mm.+ Min.	B. P. 700 mm.+ Max.	B. P. 700 mm.+ Mean	B. P. Change Am't	B. P. Change Dur.	Rel. Hum.	Air Temp.	Sea Temp.	T_a-T_s	Ocean Current Vel.	Ocean Current Direction
	° ′	° ′					mm	mm	mm	mm	h	%	°	°	°	m/d	°
Jan. 9	55 32	315 22	oc	Calm-SSE-Calm-NW-NW.N	0	3	47.1	52.4	49.8	—4.2	28	94	4.8	4.5	+0.3	7	S63W
10[10]	54 24	318 53	odfd	NW-W-NNW-N-NW	3	4	48.8	54.6	51.7	+7.5	32	96	4.2	3.6	+0.6	13	S20W
11[11]	54 04	321 30	fmdrbc	N.W-NW-SW-SSE-ESE	2	5	38.5	48.8	43.6			94	4.4	2.8	+1.6	10	S41E
12[12]	54 08	323 30	oqmf	ESE-SE-Calm	0	3	36.9	40.6	38.8	—17.7	40	97	2.8	2.9	—0.1	8	N48W
13	South	Georgia						40.9		+4.0	27						
							35.4		38.2	—5.5	9						
14	South	Georgia	upq	NW	8	9	32.5	38.3	35.4	+2.9	9	90	3.9	2.8	+1.1		
15[13]	54 16	327 11	odbcm	NW-W-SW	2	9	31.2	49.9	40.6	—7.1	26	94	3.0	2.2	+0.8	5	S88W
16[13]	54 40	331 35	odmf	N.W-NNE-NW-W-NW	3	5	45.5	49.9	47.7	+18.7	20	97	2.8	2.0	+0.8	6	S 1W
17[13]	54 36	335 52	mf	NW-WNW-NNW	4	8	38.3	45.5	41.9			98	4.2	2.7	+1.5	6	S14W
18[13]	54 33	341 39	mdf	NNW-N.W	2	8	36.3			—13.6	50	98	3.6	2.9	+0.7	7	S32W
								38.5	37.4	+2.2	11						
19[13]	54 30	344 52	mdof	W.N-W	2	4	36.3	47.6	42.0	—2.2	14	98	3.3	2.4	+0.9	12	S57W
20[13]	54 18	349 59	omf	W-NNW-N-N.W	4	6	47.6	50.7	49.2	+14.4	41	98	2.6	1.7	+0.9	24	S56W
21[14]	54 20	356 35	ofdmbc	NNW-NW-W	4	7	47.5	52.3	49.9	—3.2	15	98	1.8	1.0	+0.8	29	S47W
22[15]	54 00	1 41	bcmd	W-NW.W	5	9	52.3	57.7	55.0	+10.4	23	90	2.0	0.6	+1.4	15	S 1W
23[16]	53 33	5 33	mdos	NW.W-WNW-NNW-N.E			51.7			6.0	14						
					3	9	46.5	56.1	51.3	+4.4	9	90	2.2	0.6	+1.6	7	S52W
24[16]	53 42	9 49	odmfs	N-NNW-W.N-NW	3	5	40.7			—15.4	19	89	2.0	0.8	+1.2	17	S61W
								42.5	41.6	+1.8	15						
25[16]	54 08	15 34	sobcs	NW-NW.N-NW	5	5	39.1	41.3	40.2	—3.4	8	92	1.4	0.5	+0.9	15	S80W
26[16]	54 30	21 18	cbcod	NW-NNW-N	5	6	40.0	41.9	41.0	+2.8	28	92	1.4	0.6	+0.8	15	S4 W
27[16]	54 16	26 22	odfms	N.W-N-W.N-SW	2	6	30.5	39.3	34.9	—11.4	32	98	1.0	1.0	0.0	31	S49W
28[16]	53 40	30 57	osc	SW.W-WSW	5	6	31.8	43.7	37.8			86	1.8	1.5	+0.3	22	S18W
29	52 40	36 39	csodfq	W.S-NW.W-N.W-NW.N	6	10	35.8	44.8	40.3	+14.3	34	90	2.8	2.4	+0.4	26	S22W
30	52 45	39 12	qrmbc	NW.N-N-NW.N-N.W	6	10	30.1	35.8	33.0	—14.7	24	94	3.5	2.5	+1.0	21	S38E
31	51 38	43 05	ocmr	NW.N-W.S-NW.N	4	8	35.3	47.7	41.5	+17.6	38	90	3.5	2.5	+1.0	23	S 1E
Feb. 1	49 4	47 15	qroc	NW.N-WNW	6	10	43.7	49.3	46.5	—4.0	6	94	5.0	3.9	+1.1	19	N19E
2	48 36	50 59	ocbc	WNW-W.S-SW.W-W	4	6	48.9	57.3	53.1			86	5.2	4.6	+0.6	12	S 1E
3	48 33	55 13	bcdo	W.S-W.N-NW.N	4	6	56.7	59.0	57.8			85	5.8	5.2	+0.6	22	N59W
4	48 40	59 57	o	NW.N-N.E	4	6	57.3	59.8	58.6	+16.1	79	91	6.8	6.0	+0.8	16	N85W
5	49 01	63 44	odmrb	NNW-NW.W-SW.S-W.S	3	7	55.5			—4.3	17	93	6.1	5.2	+0.9	14	N16W
								64.0	59.8	+8.5	19						
6[17]	49 34	67 12	bcomd	W.S-N.W-NNE-WNW	3	7	48.3	63.6	56.0			89	5.3	4.8	+0.5	8	N46W
7	51 01	70 48	odqrm	W-WNW-WSW-SSW	7	10	38.3	48.3	43.3	—25.7	42	86	4.0	3.8	+0.2	21	N 8W
8	52 07	74 57	obcspq	SSW-SW-S	6	9	41.6	50.7	47.6			87	2.8	3.1	—0.3	21	N 5E

[10] Many icebergs; water temperature dropped only 0°.2 as vessel approached berg. [11] Many icebergs; off northwest coast of South Georgia.
[12] Entered Cumberland Bay, South Georgia. [13] Icebergs. [14] Icebergs; passed through a stream of small bergs. [15] Icebergs; passed 3 miles north of Lindsay I.
[16] Icebergs. [17] Passed near Kerguelen I. * See footnote, page 186.

TABLE I.—*Sea-Surface Temperature and Meteorological Observations on the Carnegie's Sub-Antarctic Cruise.*—*Continued.*

Date 1916	Noon Position S. Lat.	Noon Position E. Long.	Weather	Wind Direction* (True)	Force Min.	Force Max.	B. P. 700 mm. + Min.	B. P. 700 mm. + Max.	B. P. 700 mm. + Mean	B. P. Change Am't	B. P. Change Dur.	Rel. Hum.	Air Temp.	Sea Temp.	T_a-T_s	Ocean Current Vel.	Ocean Current Direction
	° ′	° ′					mm	mm	mm	mm	h	%	°	°	°	m/d	°
Feb. 9	51 04	77 52	bcodsq	W-WSW-SW-WSW	5	7	50.7	55.6	53.2	+17.3	44	88	3.7	4.3	—0.6	13	N46W
10	49 47	80 29	odrmq	W.N-NW-N-NE.E-E-SSE	3	9	34.6	51.7	43.2	—21.0	24	92	3.5	5.0	—1.5	17	S57W
11	47 10	83 39	oqrd	SW.S-SW.W-SSW-SW	8	8	45.3	52.1	48.7	......	......	85	5.6	7.8	—2.2	24	S67W
12	44 06	86 30	qrd	SW-SW.S-SW-SSW	7	8	52.1	59.3	55.7	......	......	82	7.5	9.8	—2.3	17	S50W
13	41 15	88 32	qcdo	S-SSW-SW.W-W.N	3	8	59.3	65.3	62.3	......	......	79	11.2	12.8	—1.6	28	S23W
14	38 18	90 26	oc	NW-NW.W-NW	5	6	65.1	66.6	65.8	......	......	77	15.2	15.4	—0.2	24	S18W
15	35 48	93 10	ocbćd	NW-NW.W-WNW-SW-SE.S	3	5	65.9	67.3	66.6	......	......	76	18.1	17.6	+0.5	23	S 9W
16	34 32	95 58	ocb	SE.S-SE.E-SE	3	4	67.3	71.8	69.6	......	......	70	16.3	17.8	—1.5	27	S85W
17	34 59	95 34	oc	SE-ESE-E.S-ESE	3	5	71.9	73.1	72.5	+38.5	163	78	15.6	17.2	—1.6	8	N59W
18	36 10	95 23	obc	E.S-Calm-E.S-NE-Calm-ENE	0	3	67.3	71.9	69.6	......	......	74	16.5	16.8	—0.3	8	N 2W
19	36 08	97 10	bcoc	Calm-E.N-SE-S-Calm	0	1	65.5	67.3	66.4	......	......	77	20.0	17.4	+2.6	10	S63W
20	37 26	97 30	ocbcq	Calm-WNW-NNW-WNW-WSW-S.W	0	5	61.3	65.5	63.4	—11.8	84	86	15.6	16.0	—0.4	9	N45W
21	39 48	99 11	qdbco	SW.S-WSW	4	7	61.5	67.3	64.4	+6.0	22	77	14.0	13.7	+0.3	21	N10W
22	42 18	100 26	bcodc	WSW-W	5	7	55.3	66.8	61.0	......	......	86	12.6	12.5	+0.1	25	N35E
23	46 07	101 33	qdmr	W.S-W-W.N-WSW-W.N	4	8	48.1	55.3	51.7	—19.2	41	94	9.6	9.4	+0.2	42	N63E
24	47 52	102 01	oc	W.S-W.N-Calm-S.W-S.E	0	4	52.1	55.3	53.7	+7.2	33	92	7.0	6.5	+0.5	31	N59E
25	47 49	103 39	ocbc	S.E-SE.S-SW W	2	5	43.3	55.3	49.3	......	......	78	6.5	6.8	—0.3	6	N 6W
26	49 58	104 51	odqh	W-SW.W-W.S	5	9	34.9	43.3	39.1	—20.4	43	87	5.1	5.6	—0.5	29	N26E
27	52 32	106 34	qdho	WSW-SW.W-WSW	6	10	35.3	43.0	39.2	+ 8.1	29	88	3.8	4.5	—0.7	30	N22E
28[18]	54 33	107 33	qdofmr	WSW-W-WNW-SW.W	3	6	25.6	42.8	34.2	......	......	97	3.9	4.0	—0.1	25	N46E
29[18]	57 08	108 29	qsdrh	WSW-W.S-W	7	10	24.6	......	......	—18.4	28	86	2.9	3.2	—0.3	23	S 3E
					......	......	......	28.1	26.4	+3.5	9	......	......		......	......	......
Mar. 1[19]	59 15	110 00	sq	W.S-SW.W-S.E-SSE	5	9	17.6	28.1	22.8	—10.5	20	94	2.0	2.4	—0.4	20	N30E
2[20]	56 54	112 23	sqdhbc	S-SSW-S-SSW	6	7	28.1	51.7	39.9	......	......	89	3.0	3.5	—0.5	23	S87W
3[21]	53 45	113 41	oc	SW.S-S.W-SW.W-W.N	4	6	51.7	57.3	54.5	+39.7	57	82	3.5	4.2	—0.7	15	S 8E
4	51 30	116 26	ocmdq	NW.W-NNW-N.E-NNW-WNW	4	8	42.1	55.6	48.8	......	......	92	5.1	5.5	—0.4	16	S18W
5[22]	49 13	120 16	qdhr	WNW-W	7	9	41.5	45.0	43.2	—15.8	39	83	6.2	7.6	—1.4	33	S44E
6[23]	46 02	122 55	qchdr	W.N-W-NW-N.W	7	10	39.8	47.5	43.6	+6.0	27	88	8.8	9.7	—0.9	16	S35E
7	45 09	125 08	qrhdl	N.W-NW-W.N-WNW	9	11	36.3	......	......	—11.2	15	88	9.8	10.8	—1.0	8	N19E
					......	......	......	48.9	42.6	+12.6	18	......	......		......	......	......
8[24]	44 58	126 01	qrlh	NNW-NW-WNW	6	10	45.1	52.3	48.7	—3.8	7	83	8.2	10.8	—2.6	7	N
9	44 11	126 34	qrchd	WNW-W-W S-W-NW	5	8	51.7	60.1	55.9	+15.0	40	76	9.9	10.8	—0.9	12	N11W
10	41 51	127 48	qdro	NW.W-NW-NW.W	5	8	57.3	58.9	58.1	......	......	90	12.2	12.6	—0.4	12	S 1E
11	39 54	129 14	bcqdm	NW.W-WNW-NW-NNW-N.E-WNW	2	6	55.5	57.5	56.5	......	......	92	13.8	14.5	—0.7	14	S 8W

[18] Aurora australis. [19] Passed one iceberg. [20] Aurora australis. [21] Aurora australis; much seaweed. [22] Aurora australis.
[23] Sea surface covered with brilliant phosphorescent bodies. [24] Aurora australis. * See footnote, page 186.

TABLE I.—*Sea-Surface Temperature and Meteorological Observations on the Carnegie's Sub-Antarctic Cruise.—Concluded.*

Date 1916	Noon Position S. Lat.	Noon Position E. Long.	Weather	Wind Direction* (True)	Force Min.	Force Max.	B. P. 700 mm. + Min.	B. P. 700 mm. + Max.	B. P. 700 mm. + Mean	B. P. Change Am't	B. P. Change Dur.	Rel. Hum.	Air Temp.	Sea Temp.	$T_a - T_s$	Ocean Current Vel.	Ocean Current Direction
	° ′	° ′					mm	mm	mm	mm	h	%	°	°	°	m/d	°
Mar. 12	40 25	130 03	bebodq	WNW-W-WSW-W.N-SW	2	5	54.7	55.7	55.2	...	...	88	14.8	14.9	−0.1	11	S[illegible]E
13	43 04	131 01	bebqrd	SW-W.N-W-W.N	4	5	49.7	54.1	51.9	...	...	81	13.0	12.7	+0.3	19	S5E
14	46 28	130 51	qrdbc	WNW-NW.W-W-SW-SW.S	5	7	40.9	49.7	45.3	−19.2	117	84	9.8	10.9	−1.1	27	S55E
15	48 42	132 52	qebcodr	SW-SW.S-W.S-NW.W-W.S	5	7	43.7	51.9	47.8	...	...	84	9.2	9.6	−0.4	21	S 8 E
16[25]	50 27	132 55	bewodmf	SW.W-WNW-NE-N-NW	1	5	46.8	55.3	51.0	+14.4	28	95	8.1	7.8	+0.3	18	S58E
17	53 44	131 51	mroqLd	NNW-WNW	6	9	40.5	...	...	−14.8	22	88	6.8	6.1	+0.7	29	S65E
					...	...	...	46.2	43.4	+5.7	16	...	...	...	...	...	...
18[26]	56 35	133 05	cqdmh	NW-N.W-NW.W	7	10	37.1	47.7	42.4	−9.1	10	86	4.8	4.4	+0.4	30	S39E
19[27]	56 48	135 36	qehbcb	NNW-WNW-W.N-WNW	6	10	47.7	59.7	53.7	...	...	87	4.6	4.2	+0.4	25	N83E
20	57 09	138 37	odb	WNW-NNW-N.W	3	5	61.1	62.1	61.6	+25.0	60	86	4.6	4.0	+0.6	12	S58W
21	56 53	143 00	cwofmd	N.W-NW.N-N-NE	3	5	51.8	59.3	55.6	...	...	95	2.6	3.5	−0.9	12	S59W
22[28]	56 47	144 47	ordfm	NE-NE.E-N-NW-N-N.E-NNW	3	5	37.3	51.8	44.6	...	...	98	4.3	3.2	+1.1	17	S83W
23	56 39	147 07	mfdsr	N-NNW-W.S-SW.W	1	6	35.4	38.5	37.0	−26.7	60	95	3.4	4.1	−0.7	5	S21E
24	54 24	151 00	ordpqe	SW-SW.S-SW	4	6	37.8	49.9	43.8	...	...	90	4.4	5.7	−1.3	5	S46E
25	52 54	154 22	oedbem	SW-W.S-NW-N-NE.N	2	4	47.7	50.9	49.3	+15.5	48	89	6.0	7.5	−1.5	11	S10W
26	52 37	156 35	odmr	NE.N-N-NW-NW.W-S.W-WSW	1	5	42.2	47.7	45.0	−8.7	33	95	7.6	8.0	−0.4	8	N77E
27	50 59	160 47	coqb	W-WSW-NW.N-WNW-W	5	7	43.3	55.1	49.2	...	...	84	8.8	9.5	−0.7	19	S72W
28	48 31	164 06	beqdo	WSW-SW-SSW-SW-SSW-W	4	5	55.1	70.3	62.7	...	...	81	9.1	10.8	−1.7	6	S70W
29[29]	47 52	167 47	ocb	W-WSW-NW.N-NW-NW.N	4	5	69.9	71.3	70.6	...	...	80	11.2	12.4	−1.2	14	N58W
30[30]	46 08	171 04	beco	NW-NW.N-WNW-W.N-NW.N	3	4	69.7	72.1	70.9	+29.9	99	86	13.0	12.0	+1.0	15	S34W
31	41 49	172 51	obce	NW.N-NW-NNW-N-NE-NNE	1	3	67.9	71.7	69.8	...	...	88	14.2	13.0	+1.2	8	S67E
Apr. 1	Lytt	elton	c	NNE-N.E	2	3	...	...	...	...	...	87	14.3	13.6	+0.7	...	...

[25] Aurora australis. [26] Aurora australis; very brilliant both morning and evening. [27] Aurora australis; very brilliant. [28] Aurora australis.
[29] Passed near Snares Ids. [30] Passing east of Stewart I. * See footnote, page 186.

LETTER TO EDITOR

BRITISH ASSOCIATION MEETINGS FOR THE DISCUSSION OF GEOPHYSICAL SUBJECTS.

The various branches of science which deal with the physical, metrical and dynamical properties of the Earth are in many ways closely inter-related, both on their theoretical and observational sides. It has too long been the case, however, that workers in each branch have pursued their investigations without being able to maintain adequate touch with what is being done in the other sections of the science. This has largely been due to the lack of a common meeting-ground at which investigators, and others who take interest in the subject, may read and discuss papers and reports, and in other ways contribute to the common advancement of our knowledge of the Earth. In order to remove this drawback the British Association for the Advancement of Science has recently appointed a Committee to arrange meetings in the coming year for the discussion of geophysical subjects, and also to co-operate with existing committees in making recommendations for the promotion of the study of such subjects in the British Empire.

The heading Geophysics, which has been adopted for want of a better title, is intended to include geodesy, terrestrial magnetism, tides, atmospheric electricity, and seismology. The Committee has in view the arrangement of two meetings before Christmas, and three or more during the first six or eight months of the ensuing year (1918), at which papers and reports on these subjects will be considered. The first meeting took place on Wednesday, November 7, 1917, at 5 p.m., in the apartments of the Royal Astronomical Society, and was presided over by the Chairman of the Committee, Sir Frank W. Dyson, the Astronomer Royal, who made a brief statement concerning the objects and future program of the meetings.

The subject of magnetic surveys was introduced by Dr. S. Chapman, who made a report on magnetic surveys and charts by land and sea throughout the world. Dr. G. W. Walker, F.R.S., gave an account of the recent magnetic survey of the United Kingdom made under the auspices of the Royal Society and the British Association. Major Lyons exhibited and described two of Gauss's heliotropes, on loan to the Science Museum.

At the second meeting, which has been provisionally appointed to take place on December 5, 1917, Prof. Arthur Schuster, Sec. R.S., will preside, and Sir Napier Shaw will open a discussion on the general constitution and condition of the atmosphere, which will be continued by Mr. Jeans and others. Among the subjects which the Committee has under consideration for report and discussion at latter meetings may be

mentioned seiches and tides; atmospheric electricity; British earthquakes; observatories; methods and instruments in connection with the various branches of geophysics; goedetic and gravity surveys; and the constitution, temperature and other physical conditions, motions and secular changes of the interior of the Earth. Papers on these and other geophysical subjects for reading and discussion at the meetings, as approved by the Committee, should be addressed to the Secretary.

The members of the Committee are Sir F. W. Dyson (Chairman), Dr. C. Chree, Col. C. F. Close, Prof. E. B. Elliott, Mr. J. H. Jeans, Prof. A. E. H. Love, Major H. G. Lyons, Prof. A. Schuster, Sir Napier Shaw, Prof. H. H. Turner, Dr. G. W. Walker, and Dr. S. Chapman (Secretary). Communications should be addressed to the Secretary at the Royal Observatory, Greenwich, S.E. 10. S. CHAPMAN.

NOTES

12. *Magneto, Electric and Allied Observations During the Total Solar Eclipse on June 8, 1918.*—Arrangements are being made by the Department of Terrestrial Magnetism and the U. S. Coast and Geodetic Survey for cooperative geophysical observations during the total solar eclipse on June 8, 1918, the path of which crosses the United States diagonally from Washington state to Florida. It may be recalled that special interest in observations of this character has been taken since the total solar eclipse of May 28, 1900. This eclipse occurred in the morning hours in the southeastern part of the United States, while the eclipse of June 8, 1918, will occur in the afternoon hours in the northwestern and western part of the United States. A unique opportunity will thus be afforded for testing some conclusions drawn from the previous eclipse. It is to be hoped that Carlheim-Gyllensköld's work in connection with the eclipse of August 21, 1914, at European stations, will become known in time to serve a useful purpose in planning any additional observations for the coming eclipse.

13 *Principal Magnetic Storms Recorded at the Cheltenham Magnetic Observatory, July 1 to September 30, 1917.*[1]

Latitude 38° 44′.0 *N.*, *Longitude* 76° 50′.5 *W. or* $5^h\ 07^m.4$ *W. of Greenwich.*

Greenwich Mean Time					Range		
Beginning			Ending		Decl'n	Hor. Intens.	Vert. Intens.
	h	m		h m	′	γ	γ
Aug. 9,	4	12	Aug. 10,	5 00	87.0	738	1139
Aug. 13,	13	27	Aug. 14,	2 00	30.3	154	64
Aug. 14,	12	20	Aug. 15,	14 00	44.9	197	224
Aug. 20,	8	21	Aug. 22,	6 00	44.0	235	216
Aug. 25,	19	40	Aug. 26,	4 00	47.6	227	96

[1] Communicated by Dr. E. Lester Jones, superintendent of the U. S. Coast and Geodetic Survey, George Hartnell, observer-in-charge.

14. Personalia. *Dr. Otto Klotz* has been appointed chief astronomer and director of the Dominion Astronomical Observatory, at Ottawa, Canada. *Dr. Edward B. Mathews* has been advanced from the post of assistant state geologist to that of state geologist of Maryland, to succeed the late Professor William Bullock Clark (see this volume, p. 147). *Roald Amundsen* has returned his various German decorations to the German minister in Christiania in protest against the German methods of submarine warfare as evidenced against Norwegian ships. We regret to record the death of *Friederich Robert Helmert* on June 15, professor of geodesy, University of Berlin, and director, Prussian Geodetic Institute and the Central Bureau of the International Latitude Service.

15. The Royal Observatory of Belgium. The following description of the present work at the *Uccle Observatory* is given by *F. P. Brackett* in the *Publication of the Astronomical Society* of Pomona College:

> Mr. Brackett was in Brussels in the summer of 1916. One of his fellow-passengers on the trip to Europe was the well-known Belgium astronomer M. G. van Biesbroeck, a member of the staff of the Royal Observatory, who had been spending a year at the Yerkes Observatory. Although M. van Biesbroeck had obtained permission from the German authorities before visiting America, he was stopped at the frontier and has not yet been allowed to return to his work at Uccle. With some difficulty Mr. Brackett secured permission to visit the observatory. It is closely guarded by German soldiers, and the only observations allowed are those for the time service; these must be made at dusk or dawn. The observatory has been under the direction of Prof. Stroobant, in the absence of the director, M. Lecointe, who, as a reserve officer of the Belgian artillery, has been interned in Holland since the fall of Antwerp. He is now living at The Hague, on parole.

16. The Samoa Observatory. As will have been noticed by the readers of this Journal, Dr. Angenheister, the observer-in-charge, is allowed by the New Zealand military authorities to continue the work of the Apia Observatory, and to send out scientific communications.

17. Concerning Duties Performed by Various Magneticians.—*Eric Webb* who, it will be recalled, performed very meritorious magnetic work on the Mawson Antarctic Expedition, is on military duty in France as a major in the Australian Engineers. His card of the season's greetings, 1917 and 1918, contains the following suggestive lines from Omar:

> Dear Friend, if you and I could but conspire
> To grasp this sorry scheme of things entire,
> Would we not shatter it to bits, and then
> Remould it nearer to our heart's desire?

Lieut. E. Kidson, R. E., of Christchurch, New Zealand, who led several notable magnetic expeditions under the auspices of the Department of Terrestrial Magnetism, is carrying on upper air researches in connection with his military duties. *Lieut. H. F. Johnston*, R. N., of Toronto, Canada, is utilizing the experience gained as an observer on the *Carnegie*, having been assigned to duty with the Compass Department of the British Admirality. *L. F. Richardson*, formerly superintendent of the Eskdalemuir Observatory, who is performing duty with the motor ambulance service in France, has sent us a circular which is being issued

in Great Britain by his brother, *Gilbert H. Richardson*, concerning the need for standardizing auxiliary international language. The declaration for which signatures are requested, is as follows:

We, the undersigned, are agreed that there is a need for an auxiliary international language similar to Esperanto or to Ido; and we are further agreed that there should be only one such language, and that it should be supported by an authority which would command general respect. We, therefore, hereby express the wish that, at the close of the war, a permanent International Commission should be appointed and financially supported by the Governments of the Powers, for the purpose of settling then and thenceforward, all questions relating to the grammar, vocabulary, pronunciation and orthography of the auxiliary international language.

A Committee on Navigation and Nautical Instruments was appointed last June by the National Research Council, at the request of the Counsel of National Defense, for the purpose of advising the United States Shipping Board on nautical instruments and navigational methods. This committee consists of the following: *L. A. Bauer* (Chairman), *J. S. Doddridge*, U. S. N., *R. L. Faris* and *Roy Y. Ferner*. These gentlemen represent, respectively, the Department of Terrestrial Magnetism of the Carnegie Institution, the Bureau of Navigation and the Naval Observatory, the Coast and Geodetic Survey, and the Bureau of Standards. *W. J. Peters*, *J. A. Fleming*, *J. P. Ault* and other members of the Department of Terrestrial Magnetism are rendering this committee effective aid in its work.

18. Millikan's "The Electron." [1] In this useful little volume Prof. *R. A. Millikan*, whose contributions to the present exact knowledge of the properties of the electron are well known, suggestively presents the evidence for the atomic structure of electricity, with a description of some of the most significant properties of the electron, accompanied by a discussion of the bearing of these properties on the structure of the atom and the nature of electro-magnetic radiation. The author enhances the value of his treatment by a critical analysis of the available quantitative experiments upon which our conclusions are based. The volume is commended to those who wish to familiarize themselves quickly and accurately on the physics of the electron.

The following *summary of the most important physical constants* "the values of which it has become possible to fix,[2] within about the limits indicated through the isolation and measurement of the electron," is taken from page 238:

The electron	$e = (4.774 \pm 0.005) \times 10^{-10}$
The Avogadro constant	$N = (6.062 \pm 0.006) \times 10^{23}$
Number of gas molecules per cc. at 0° C., 76 cm. . .	$n = (2.705 \pm 0.003) \times 10^{19}$
Kinetic energy of translation of a molecule at 0° C. .	$E_0 = (5.621 \pm 0.006) \times 10^{-14}$
Change of translational molecular energy per °C. . . .	$\epsilon = (2.058 \pm 0.002) \times 10^{-16}$
Mass of an atom of hydrogen in grams	$m = (1.662 \pm 0.002) \times 10^{-24}$
Planck's element of action	$h = (6.547 \pm 0.013) \times 10^{-27}$
Wien constant of spectral radiation	$C_2 = 1.4312 \pm 0.0030$
Stefan-Boltzmann constant of total radiation	$\sigma = (5.72 \pm 0.034) \times 10^{-12}$
Grating spacing in calcite	$d = 3.030 \pm 0.001$Å

[1] The electron. Its isolation and measurement and the determination of some of its properties. Chicago, University of Chicago Press, 1917 (xii + 268). 19 cm.

[2] See *Proc. Nat. Acad. Sci.*, III (1917), *236*; also *Phil. Mag.*, July, 1917.

19. Closing of the Barrackpore Observatory. The following extract is taken from pages 92-93 of volume 9 (1914-15) of the "Records of the Survey of India":

The committee which assembled in March 1914 to discuss the position of the magnetic survey and to advise as to its future programme were of opinion that the maintenance of the observatories of Dehra Dūn, Kodaikānal, Toungoo and Alibāg in continuous operation should give adequate data for determining the magnetic elements at any time at any place in India, and that the Barrackpore observatory might therefore be closed. On the 26th April 1915 observations at this observatory were discontinued after the repeat stations, whose values are dependent on the Barrackpore observatory for disturbance connections, had been permanently marked and observations at them completed. The magnetographs were then dismantled by the officer in charge and the buildings made over to the Bengal Public Works Department on the 3rd May 1915.

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TERRESTRIAL MAGNETISM
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ATMOSPHERIC ELECTRICITY

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Conducted by
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TABLE OF CONTENTS

MARCH, 1918

JUNE, 1918

SEPTEMBER, 1918

DECEMBER, 1918

Terrestrial Magnetism
and
Atmospheric Electricity

VOLUME XXIII MARCH, 1918 NUMBER 1

RELATION BETWEEN THE SECULAR VARIATION OF THE EARTH'S MAGNETISM AND SOLAR ACTIVITY.[1]

BY L. A. BAUER.

1. In a previous paper entitled "Solar Radiation and Terrestrial Magnetism," the possibility was pointed out that irregularities in the annual changes of the Earth's magnetic elements, the so-called secular variation, might be associated with such manifestations of solar activity as are revealed to us by changes in the solar constant of radiation.[2] As the result of a preliminary investigation, the following conclusion was reached in that paper:

> If the quiet-day magnetic effect were to persist throughout the year, it would cause a secular variation fully 10 times that generally observed. However, the quiet days are in the minority, being exceeded 3 times and more by unquiet days, on which the magnetic effect is of an opposite or compensating kind to that of the quiet day. Since these acyclic effects appear to be associated with solar changes and since the latter are not periodic, but more or less sporadic, there is an outstanding effect at the end of the year which causes an irregularity in the regularly-progressing secular change. Accordingly, there should be found some correspondence between annual changes of the solar constant and annual magnetic changes. This is found to be the case. Since the solar-constant changes occur only approximately in accordance with sun-spot activity, and since the magnetic changes are found to conform closely to those in the solar constant, an explanation is found as to why the irregularities in the magnetic secular change do not always synchronize with changes in solar activity as measured by the sun-spot numbers, nor correspond in magnitude to them.

[1] Résumé of papers presented before the American Philosophical Society, April 14, 1916, and the Philosophical Society of Washington, January 22, 1916, with amplifications to date. Fuller publication will be made in a forthcoming volume of "Researches of the Department of Terrestrial Magnetism."

[2] *Terr. Mag.*, vol. 20, 1915, pp. 155 and 157.

The present paper examines more fully into this interesting matter.

FORMULAE.

2. The formulae for the function, G, used in this investigation, were developed in my article on "The Local Magnetic Constant and its Variations."[3] Supposing that the magnetic elements D (declination), I (inclination), and H (horizontal intensity), observed at any given place at a particular time, arise from a uniform magnetic system wholly below the Earth's surface, we have:

$$G = \sqrt{H^2 + \frac{1}{4} Z^2} = \sqrt{X^2 + Y^2 + \frac{1}{4} Z^2} \qquad (1)$$

$$dG = \frac{H}{G}\, dH + \frac{1}{4}\frac{Z}{G}\, dZ = \frac{X}{G}\, dX + \frac{Y}{G}\, dY + \frac{1}{4}\frac{Z}{G}\, dZ \qquad (2)$$

Here X, Y and Z are the resolved rectangular magnetic components (X, +north; Y, +east; Z, +downwards). If they were solely the result of the supposed uniform magnetic system, then while they themselves would vary over the Earth, with geographic position of the station to which they apply, G on the other hand would remain constant. Furthermore, if the dX-, dY-, dH- and dZ-variations resulted merely from a change in the direction of the axis of the assumed magnetic system, then while these quantities again would vary with geographic position, the variations would have to occur in such a manner so that $dG=0$. If for the case supposed, dG is not always zero, it would imply that the variations in X, Y, H and Z were caused not simply by a change in direction of magnetic axis but also by a change in the magnetic moment, or intensity of magnetization, of the system. *Hence, for a uniform magnetic system whose potential, V, is of the simple type:*[4]

$$V = \frac{R^2}{r^2}\,(g_{10} \cos u + g_{11} \sin u \cos \lambda + h_{11} \sin u \sin \lambda) \qquad (3)$$

the quantity, G, would remain constant over the Earth, not only for any particular time, but for all time, if the secular variation to which the system was subject were caused alone by changing direction of magnetic axis, and not also by changing magnetic moment. For this system we have at once:[4]

$$G = \frac{4}{3}\pi\rho = \frac{M}{R^3} = \sqrt{g^2_{10} + g^2_{11} + h^2_{11}} \qquad (4)$$

[3] *Terr. Mag.*, vol 19, 1914, pp. 113-116.

[4] *Idem*, vol. 19, 1914, p. 114.

ρ is the intensity of magnetization, M, the magnetic moment, and g_{10}, g_{11}, h_{11}, are the resolved components of ρ, parallel, respectively, to the axis of rotation and to two rectangular axes lying in the equatorial plane, one of which is in the meridional plane of Greenwich and the other in the meridional plane of 90° east.

3. If G is not the same for all places and all times, then its departures from some mean value are a measure of the following: (a). The extent to which the Earth's actual magnetic system departs at any particular time from the simple type defined by (3); (b). The extent to which the observed secular variation of the Earth's magnetic system is caused by changes in intensity of magnetization. For the 8 observatories entering into the present investigation (see Tables 5 and 6), differing so greatly from each other in magnetic latitude as do Sitka (Alaska) and Alibag (India), the maximum geographic variations from the respective mean values were in 1910: For H, 45%; for Z, 51%; for F, 23%; for G, 14%. The maximum time variations from the respective mean values were for such a station as London, for example, during the period 1891 to 1915 (see Table 3): For H, 0.9%; for Z, 0.7%; for F, 0.5%; for G, 0.3%.

4. Were it readily possible to make at any desired time a harmonic analysis of the Earth's magnetic state, then the required conclusions could be drawn most satisfactorily from the values of the various harmonic coefficients for the successive periods of time. Such a course, however, will not be feasible for a long time to come, and plans which I had formulated for an early realization of such a project have had to be postponed because of the present unfortunate world-conflict. Instead then of obtaining an analysis by combined treatment of magnetic variations for a sufficient number of stations distributed uniformly over the Earth, simple, rapid analyses of the variations are made *separately* for each station by means of the function G. Conclusions are then drawn, more or less tentatively, from an examination of the individual results at stations, encircling the Earth, as far as the available data permit. In brief, by taking a sufficient number of stations in various parts of the Earth, we hope to eliminate, in some degree at least, from our general conclusions, the effects (a), or the local peculiarities.

5. The reasons given in the preceding paragraphs may suffice for the use of the rapidly-derived function G. A word of warning was given, however, in the paper in which this function

was developed, which it will be well to repeat here:[5] *The local magnetic constant, G, is the value derived from supposing the magnetic elements at any one station to arise solely from a uniform, sub-surface, magnetic system. A change in this constant, arising from changes in the local magnetic elements, periodic or otherwise, is to be interpreted first only as an* apparent *change of the entire Earth's field. From the distribution of the local changes over the Earth is to be determined the actual change of the entire Earth's field.*

6. An observed magnetic variation may be made up of three parts: (I) effects caused by a sub-surface potential system of magnetic or electric forces; (II) effects caused by a super-surface potential system; and (III) effects caused by a non-potential system, e. g., electric currents passing perpendicularly through the Earth's crust. The effects from system (III) are often subordinate to those from systems (I) and (II). The relative importance of (I) and (II) depends upon the particular variation considered; they are frequently interrelated.

7. According to the definition of G, the variations, dG, would be those caused by system (I) were it possible to separate the internal from the external effects in the dH- and dZ-variations *before* the dG-values were computed. This, however, is not readily possible. If the dG's were caused solely by an external system (II) of the simple harmonic-type (3), then we should have:

$$G_e = \sqrt{H^2_e + Z^2_e} = F_e \tag{5}$$

$$d\,G_e = d\,F_e = \frac{H_e}{G_e}\,d\,H_e + \frac{Z_e}{G_e}\,d\,Z_e = \frac{X_e}{F_e}\,d\,X_e + \frac{Y_e}{F_e}\,d\,Y_e + \frac{Z_e}{F_e}\,d\,Z_e \tag{6}$$

8. Let us designate by G_i and G_e the functions arising, respectively, from simple internal and external potential systems. It will be noticed from (5) that for the supposed external uniform magnetic system the function G_e is directly equal to the total intensity, F_e, and that the latter is constant at all points inclosed by the surface bounding the external system, for the obvious reason that the force inside a uniformly magnetized sphere is uniform.

9. As stated, what we actually observe are not the variations dG_i and dG_e, separately, but the *combined* quantities dG. From an examination of the dG's over the Earth we can determine,

[5] *Terr. Mag.*, vol. 19, pp. 115, 116.

however, to some extent, whether the quantities have arisen solely from an internal system, or solely from an external system, or from a combined system.

10. To have some convenient form of notation, let us arbitrarily set for the present:

$$g = dG = \frac{H}{G}\, dH + \frac{1}{4}\frac{Z}{G}\, dZ \tag{7}$$

$$f = dF = \frac{H}{F}\, dH + \frac{Z}{F}\, dZ \tag{8}$$

The theoretical significance of the differences in the values found later for the quantities g and f will be set forth in subsequent paragraphs.

11. *Effects from changing directions of magnetization* will be considered in a future paper. *The chief purpose of the present investigation is to find out, if possible, how the intensity of magnetization of the Earth may vary and how these changes may be related to changes in solar activity.* For convenience of reference, conclusions of particular interest here are cited from some of my previous investigations.

Some Previous Conclusions.

12. *Concerning the secular variation (1904).*[6] If we consider simply that portion of the Earth's magnetism which may be regarded as equivalent to a uniform magnetization about a diameter inclined approximately 11° to the axis of rotation, then it appears that this portion is subject to a secular variation arising from systems of magnetic or electric forces two of which are as follows:

a. A magnetic system situated *below* the Earth's surface, its axis being directed about opposite to that of the primary internal field and displaced in longitude at present about 68° to the west. Chiefly as the result of this demagnetizing system, the Earth's magnetic moment is at present being diminished by about 1/2400 part annually.

b. A magnetic system situated *above* the Earth's surface, whose axis is directed almost transverse to the axis of rotation and is displaced in longitude at present about 151° to the west of that of the primary internal field, and about 83° to the west of that of the internal secular variation system. This system plays an important part in the secular variation of the magnetic declination.

The secular variation of the Earth's magnetism is caused not

[6] *Terr. Mag.*, vol. 9, 1904, p. 186.

only by a change in the direction of the magnetization, but likewise by a change in the intensity of magnetization.

13. *G-Effects associated with solar activity (1909-1914).*[7] The deductions from these earlier investigations of chief interest, as derived from a comparison of the solar curves (1906-1909) with changes shown in the local magnetic constant, are the following:

a. It is seen[8] that *an increase in solar activity is accompanied by a decrease in the local magnetic constant,* and this is consistently shown by observatories as remote from one another as is Honolulu from Cheltenham. (A similar result has been obtained from an investigation of some special magnetic storms, *e. g.* the very severe one of October 30-November 1, 1903. The depressing or diminishing effect of this storm on the local magnetic constant continued for fully two months after the apparent subsidence of the storm. This fact was announced at the 1908 meeting of the American Association for the Advancement of Science held at Baltimore.)

b. It should not be argued (1909) that the apparent diminution in the local magnetic constant implies at once an actual diminution in the strength of the Earth's internal magnetic field. This we can not conclude, as yet, for the effect actually observed is a resultant one due to the combined changes in the Earth's internal and external magnetic systems—i. e., we have the sum of two quantities not as yet the individual parts, these being only obtainable from a mathematical analysis. All we may say now is that the magnetic effect associated with an increase of solar activity is apparently equivalent, in general, to a diminution in the intensity of the Earth's magnetic field, supposing the latter to result primarily (as is actually the case) from an internal system of magnetic or electric forces. Which of the two parts—whether the internal or the external part—is the more predominant or how related to its parent system must be reserved for the future analysis.

c. To afford some basis of comparison (1909) of the possible change in the local magnetic constant with solar activity, the following approximate data are given. The maximum change shown in the curve, viz., between the dates February 1, 1907, and February 1, 1908, attributable to change in solar activity, amounts to about 1/1000 part of the value of the magnetic constant; however, this may be exceeded during the actual progress of individual magnetic storms. The average annual change in the local magnetic constant, due to the secular change in the magnetic elements,

[7] *Terr. Mag.*, vol. 19, 1914, p. 119.

[8] *Idem*, vol. 19, 1914, Plate VI, curves (8) and (9).

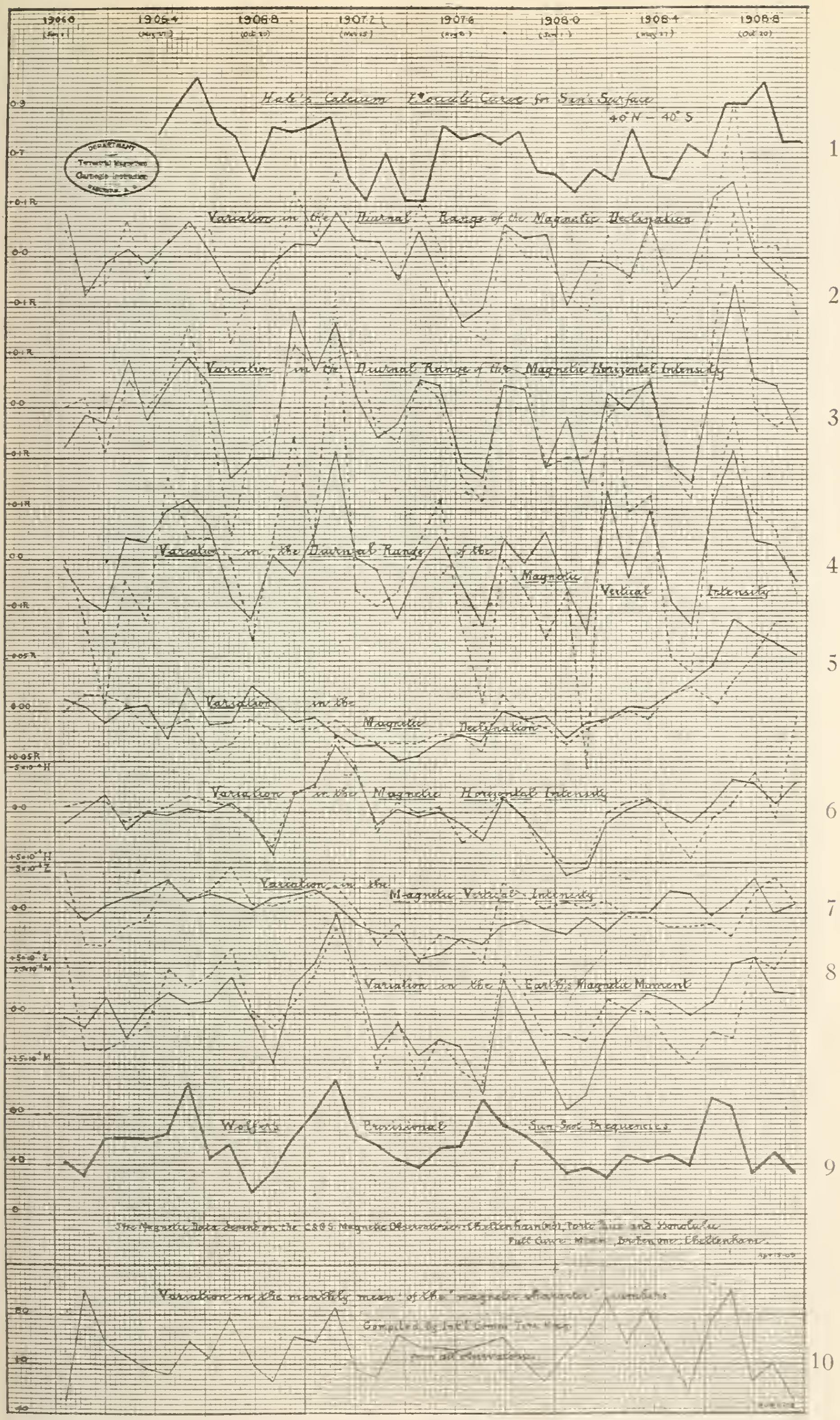

FIG. 1.—Changes in Solar Activity and in Terrestrial Magnetism, 1906-1909.

at the three observatories, Cheltenham, Porto Rico, and Honolulu, amounts to about 1/800 part of the value. The average diurnal variation in the magnetic elements produces a range in the local magnetic constant of about 1/1250 part, and the average seasonal or annual variation, a range of about 1/2500 part. On account of the diurnal variation, G is, on the average, *diminished* during the daylight hours, the largest negative change occurring on the average for the year near 11 A. M.

d. See conclusion cited in paragraph 1.

Dependence of Secular Variation upon Sun-spot Cycle.

14. The conclusions cited in paragraph 13, announced at the April 1909 meeting of the American Philosophical Society, had already shown that for the period of investigation, 1906-1909, there was a close relation between variations in G and Wolfer's sun-spot numbers. The comparisons were made from month to month for the 3-year period. Fig. 1 is a reproduction of the diagram[8] exhibited at that meeting. As stated in the conclusion cited, an increase in sun-spottedness was, in general, accompanied by a decrease in G. (Compare curves 8 and 9.) Equally as close relationships as those for G (curve 8) were not exhibited between the sun-spot curve (9) and the changes in the absolute magnetic elements, D (curve 5), and the vertical intensity, Z (curve 7). The H-curve (6) ran closely parallel with the sun-spot curve (9), it differing, for the period and particular stations considered, not markedly from the G-curve. We shall now reinvestigate the phenomenon disclosed during the period 1906-1909 on the basis of data extending over one to two-and-a-half sun-spot cycles.

15. The well-known director of the Colaba and Alibag observatories of India, N. A. F. Moos, in his discussion of the *Bombay magnetic observations, 1846-1905*,[9] drew various curves which showed the dependence of changes in the absolute magnetic elements upon the sun-spot cycle. His conclusions were in general agreement with the facts stated in the previous paragraph. The curves in Fig. 2 represent the differences (O-C) between the observed and computed values of the magnetic elements, D, I, Z, H, and F for the period of accurate observations, 1888-1905, at Colaba, Bombay. The computed values were obtained by Moos from a quadratic formula of the type (9). On the basis of his formulae, I have computed the G-residuals, using formula (2). The various quanti-

[9] Moos, N. A. F.: *Magnetic observations made at the Government Observatory, Bombay, for the period 1846 to 1905*, Pt. II, Bombay, 1910.

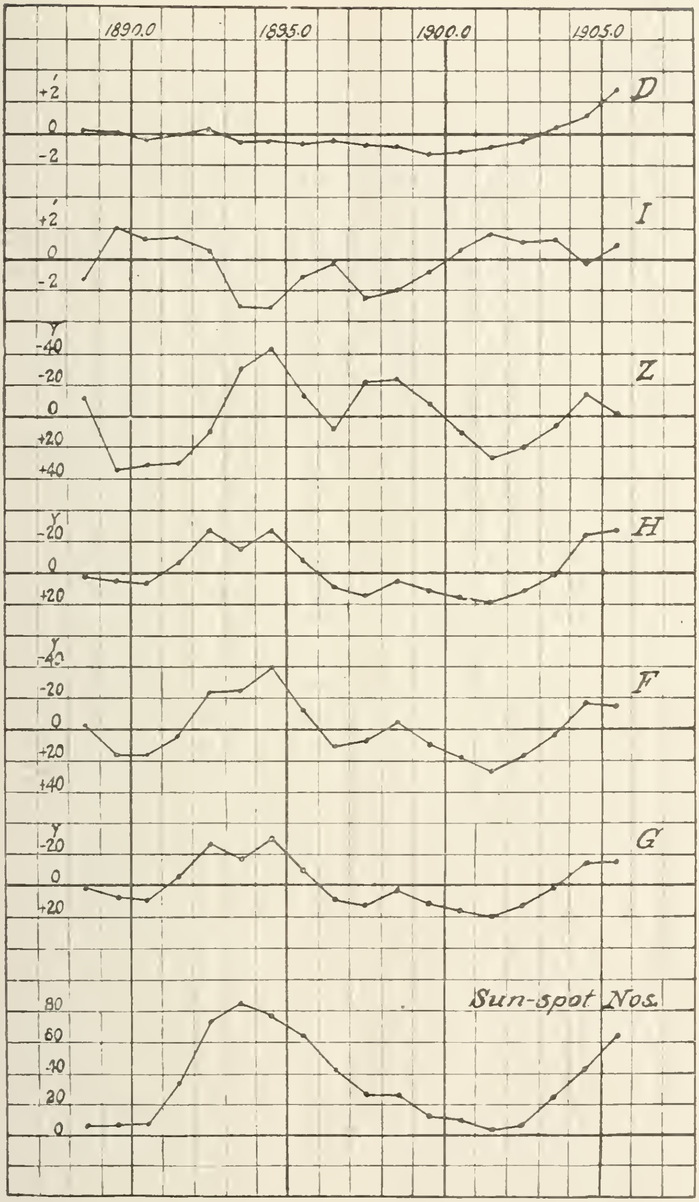

FIG. 2.—Curves Showing the Effects of Sun-spot Activity on the Absolute Magnetic Elements at Colaba, Bombay, 1888-1905.

ties[10] used for the curves in Fig. 2 are given in Table 1. A very close relationship between curves H, F, G and that of the sun-spot numbers (SN) is shown. The parallelism with the SN-curve is best shown by the H- and the G-curves; the latter two curves happen to be practically identical, because for Colaba the term $\frac{1}{4}\frac{Z}{G}dZ$ in (2) is almost negligible in comparison with the $\frac{H}{G}dH$-term.

It is further seen that while curves for the D, I, and Z show periodicities, the maxima and minima points do not synchronize, in general, with those of the SN-curve.

Attention should be directed further to the fact that the intensity curves Z, H, F, and G have been plotted so that an increase in intensity would be shown by a downward trend of the curve, whereas the sun-spot numbers increase upwards. The parallelism of H, F and G with the SN-curve, accordingly, expresses the fact stated in paragraph 14, that *an increase in sun-spottedness is accompanied by a decrease in magnetic intensity.*

Table 1.—*Differences (O-C) between observed and computed magnetic quantities at Colaba, Bombay, 1888-1905, based on Moos's formulae.*

No.	Date	SN	Differences (O−C) for					
			D	I	Z	H	F	G
			′	′	γ	γ	γ	γ
1	1888.5	6.8	+ .13	−1.5	−11.4	+ 2.0	− 2.0	+ 1.0
2	89.5	6.3	+ .07	+2.0	+36.0	+ 5.0	+17.0	+ 8.1
3	90.5	7.1	− .22	+1.4	+31.6	+ 6.0	+16.4	+ 8.7
4	91.5	35.6	− .07	+1.6	+30.0	− 7.0	+ 3.7	− 4.2
5	92.5	73.0	+ .12	+0.6	+ 9.3	−28.0	−23.1	−26.8
6	93.5	84.9	− .38	−3.1	−31.7	−15.0	−24.9	−17.6
7	94.5	78.0	− .30	−3.2	−43.0	−27.0	−40.1	−30.5
8	95.5	64.0	− .60	−1.3	−14.2	− 8.0	−12.4	− 9.2
9	96.5	41.8	− .33	−0.1	+ 7.9	+ 9.0	+11.2	+ 9.6
10	97.5	26.2	− .65	−2.8	−22.0	+15.0	+ 6.6	+12.8
11	98.5	26.7	− .82	−2.0	−23.2	+ 5.0	− 3.2	+ 2.8
12	99.5	12.1	−1.30	−0.8	− 7.4	+12.0	+ 8.8	+11.1
13	1900.5	9.5	−1.12	+0.6	+11.5	+16.0	+18.9	+16.7
14	01.5	2.7	− .87	+1.7	+26.5	+18.0	+26.0	+20.1
15	02.5	5.0	− .42	+1.2	+20.5	+11.0	+17.3	+12.6
16	03.5	24.4	+ .35	+1.4	+ 6.3	+ 1.0	+ 3.1	+ 1.6
17	04.5	42.0	+1.07	−0.2	−14.7	−14.0	−18.1	−15.1
18	05.0	63.5	+2.92	+0.9	− 0.6	−16.0	−15.2	−15.8

[10] For some of the columns, the sums of the + and − quantities do not always quite balance, for the reason that they are taken from Moos's adjusted series which may begin at times prior to 1888.5.

16. Adolf Schmidt's elaborate and suggestive discussion[11] of the *Potsdam magnetic observations for the period 1891-1911*, was received just shortly before mail service with the United States was interrupted; it is thus possible to include in this paper some interesting curves which he drew and which are found to bear on our subject. Fig. 3 reproduces the differences (O-C), derived by Schmidt, between the observed and computed values for the magnetic quantities, D, I, X, Y, Z, H and F, at Potsdam, 1891-1911. Schmidt also used a formula of the type (9). From his residuals for H and Z, I have computed those for G, using formula (2). The various quantities will be found in Table 2. The G-curve

TABLE 2.—*Differences (O-C) between observed and computed magnetic quantities at Potsdam, 1891-1911, based on Schmidt's formulae.*

No.	Date	SN	Differences (Obs'd-Comp'd) for D	I	X	Y	Z	H	F	G
			′	′	γ	γ	γ	γ	γ	γ
1	1891.0	18.5	−5.6	−3.6	+43.4	−39.0	− 8.9	+49.4	+11.6	+29.1
2	92.0	57.6	−2.7	−1.3	+ 8.3	−16.4	−18.5	+11.0	−12.5	+ 0.2
3	93.0	77.5	−1.4	+0.1	+ 2.5	− 8.1	+11.3	+ 3.9	+12.0	+ 6.9
4	94.0	**87.2**	−0.3	+1.0	− 8.9	− 0.3	+13.2	− 8.7	+ 8.6	− 0.7
5	95.0	70.1	+1.2	+1.0	−15.0	+ 9.2	− 2.3	−16.4	− 8.7	−11.7
6	96.0	51.6	+2.3	+1.4	−14.8	+15.3	+ 7.7	−17.2	+ 0.2	− 8.4
7	97.0	33.7	+2.8	+1.1	−12.2	+17.8	+ 2.4	−15.1	− 3.8	− 9.0
8	98.0	26.7	+2.8	+1.2	− 9.4	+17.4	+14.1	−12.3	+ 8.0	− 2.8
9	99.0	20.2	+2.5	+1.0	− 8.3	+15.4	+ 9.4	−10.9	+ 4.2	− 3.7
10	1900.0	10.9	+2.1	+0.4	− 0.6	+11.9	+ 7.4	− 2.7	+ 5.7	+ 1.0
11	01.0	5.1	+1.4	+0.1	+ 9.9	+ 6.1	+24.1	+ 8.7	+25.6	+14.8
12	02.0	*2.6*	+0.5	−0.8	+10.1	+ 0.9	− 3.7	+ 9.7	+ 0.5	+ 5.0
13	03.0	11.2	−0.6	−1.4	+13.6	− 5.7	−16.2	+14.4	− 9.0	+ 3.4
14	04.0	34.5	−1.3	−0.6	+ 2.9	− 7.7	−11.5	+ 4.2	− 8.8	− 1.5
15	05.0	51.6	−2.1	−0.8	+ 7.9	−12.9	− 4.6	+10.0	− 0.2	+ 4.9
16	06.0	**62.1**	−2.7	−0.9	+ 4.6	−16.0	−13.4	+ 7.3	− 9.4	− 0.3
17	07.0	59.2	−2.9	−0.7	+ 1.7	−16.2	−12.5	+ 4.5	− 9.7	− 1.7
18	08.0	51.0	−3.1	−0.3	− 3.0	−16.7	− 9.8	− 0.1	− 9.0	− 3.8
19	09.0	49.6	−2.1	+0.3	− 9.6	− 9.8	− 6.1	− 7.8	− 8.7	− 7.4
20	10.0	32.4	−0.5	+0.6	−10.0	− 1.0	+ 0.3	− 9.6	− 3.5	− 6.2
21	11.0	12.4	+1.6	+0.5	− 4.9	+ 9.9	+ 2.1	− 6.5	− 0.7	− 3.5

has been plotted first with intensity-ordinates increasing upward, to correspond with the curves as drawn by Schmidt, and next with intensity ordinates increasing downwards. The closest parallelism with the sun-spot (SN) curve is again shown by the curves for

[11] SCHMIDT, ADOLF: *Ergebnisse der magnetischen Beobachtungen in Potsdam und Seddin, in den Jahren, 1900-1910*. Berlin, 1916.

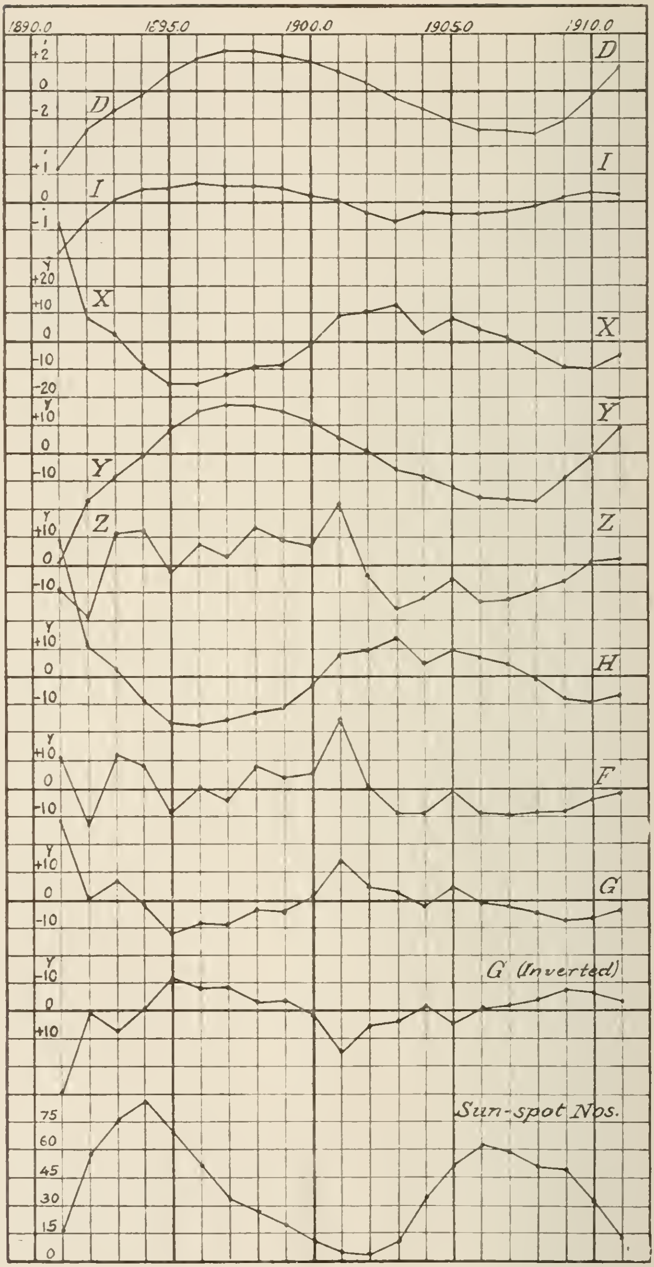

Fig. 3.—Curves Showing the Effects of Sun-spot Activity on the Absolute Magnetic Elements at Potsdam, 1891-1911.

G (inverted) and H, if inverted; thus we have once again revealed the fact that *decreasing magnetic intensity corresponds with increased sun-spottedness.*

17. An inspection of the Potsdam curves shows that they all exhibit a periodicity closely approaching the sun-spot cycle, but the maxima and minima for some, especially for D, I and Y, do not always fall close to those for the SN-curve. This fact may suggest a cause for the discordant results reached by some investigators

Leyst, for example, found that the secular change of declination was largely dependent upon sun-spottedness.[12] Chree, on the other hand, reached diverse conclusions as dependent upon declination-data at the Kew Observatory. The sun-spot effect on the magnetic elements is a cyclic phenomenon and is accompanied by effects resulting from momentary changes both in the direction and in the intensity of the Earth's magnetization. It does not necessarily follow, therefore, that changes in an angular magnetic element, such as the declination, should run entirely synchronous courses with the sun-spot curve. I hope to enter into this matter more fully in a future paper; suffice it to say here that both Leyst and Chree may be correct for the cases and periods investigated by them, respectively.

18. For Potsdam, Fig. 3, the maximum easterly (+) difference in D of $2'.8$ occurred about 1897.5; the maximum westerly (−) difference of $3'.1$ occurred in 1908.0. The amplitude of the cyclic change was thus about $6'$, and the semi-period, about 10.5 years. The amplitude for the I-curve was $2'.8$, and the semi-period was about 7 years, or about the semi-sunspot-cycle.

19. We will now enter more seriously upon our problem. Suppose we have the *annual values of the magnetic elements* as obtained by continuous registration at an observatory for a period of years. For the reasons already stated let us confine our present investigation to changes in the local magnetic constant, G, and in the total intensity F. If our series does not extend over more than 2 or 3 decades, experience has shown that an empirical formula of the following type will suffice:

$$G_c = G' + x + y(T - T') + z(T - T')^2 \qquad (9)$$

G' is the observed value at the time T', x represents a correction to be applied to G' to obtain the value of G which would pertain

[12] Bull. de la Société Impér. des Naturalistes de Moscou, 1909, pp. 100-162.

if disturbing causes not represented by (9) did not exist. G_c is the computed value at the time T, and x, y, and z are coefficients to be determined by application of the method of least squares. Similarly we have:

$$F_c = F' + x + y(T - T') + z(T - T')^2 \qquad (10)$$

Having derived the computed values of G or F from the established empirical formulae, the differences (O−C), observed—computed value, are next obtained. These are the quantities g and f in the differential formulae (9) and (10). For any station at which some H- and Z-expressions had already been established, as was the case for Colaba and Potsdam, we may apply at once formulae (7) and (8), to get g and f.

20. The process followed will be made clear by an example. For this purpose we select the series of *observations at Kew Observatory for the period 1891 to 1915*. We have endeavored to make the series as homogeneous as possible by applying to the values of H and Z, prior to 1908, corrections determined and communicated by Chree. The mean annual values of H, Z, and the derived quantities G (formula I) and F, as based upon results from the registrations of 5 quiet days in each month, are given in Table 3 (columns 4, 5, 6, and 11). Wolfer's observed sun-spot numbers will be found in column 3. Columns 7, 8, 9, and 10 contain the residuals, g, obtained by subtracting from the observed values of G in column 6 the computed ones, derived from the respective formulae I, Ia, Ib, and Ic, given on page 16. Similarly, columns 12, 13, 14, 15 contain for the various formulae the residuals, f, or the differences between observed and computed values of F.

First the formula (I), containing no sun-spot term, was established and next the g-quantities in column 7 were derived. Looking down columns 7, a remarkable run of signs will be observed, closely paralleling the run of the sun-spot numbers in column 3. The upper curve in Fig. 4, represents the G-differences, or the quantities g. By comparison with the sun-spot curve, the fourth one from the top, a parallelism is evident, but there is also shown a lag in the g-curve, amounting on the average to about 3 years.

In formula Ia, a sun-spot term was introduced, assuming no lag of magnetic curve; in Ib, a lag of 2 years was assumed, and in

TABLE 3.—*Values of G and F, and of the residuals (g, f) for Kew, 1891-1915.*

1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.	13.	14.	15.
			Observed			g=O'd-C'd G				Obs'd	f=O'd-C'd F			
No.	Date	SN	H	Z	G	I	I*a*	I*b*	I*c*	F	I′	I′*a*	I′*b*	I′*c*
			γ	γ	γ	γ	γ	γ	γ	γ	γ	γ	γ	γ
1	1891.5	35.6	18187	44023	28553	+27	+32	+21	+21	47632	+26	+36	+21	+19
2	92.5	73.0	198	4006	553	+ 9	+ 6	0	+ 1	620	+13	+ 7	+ 7	+ 5
3	93.5	**84.9**	232	3979	565	+ 3	− 1	+ 1	− 5	609	+ 3	− 9	+ 2	− 5
4	94.5	78.0	245	960	566	−11	−15	− 2	−10	596	− 7	−18	− 2	− 6
5	95.5	64.0	272	946	578	−12	−15	− 2	+ 1	593	− 6	−13	+ 2	+ 8
6	96.5	41.8	303	923	589	−13	−13	− 4	+ 4	585	− 8	− 6	− 1	+10
7	97.5	26.2	336	890	597	−15	−12	− 9	− 1	566	−19	−12	−15	− 4
8	98.5	26.7	358	872	604	−16	−14	−16	− 8	558	−17	−12	−17	− 8
9	99.5	12.1	387	837	609	−18	−14	−22	−17	536	−28	−17	−30	−27
10	1900.5	9.5	422	818	625	− 6	− 2	−10	−11	533	−18	− 7	−20	−23
11	01.5	*2.7*	445	790	629	− 5	0	−13	−10	517	−19	− 6	−24	−24
12	02.5	5.0	469	795	647	+11	+16	+ 3	+ 1	530	+11	+22	+ 6	+ 1
13	03.5	24.4	482	770	647	+12	+13	+ 3	+ 1	512	+12	+14	+ 5	0
14	04.5	42.0	498	759	652	+20	+17	+ 9	+ 6	508	+28	+23	+22	+14
15	05.5	**63.5**	504	727	643	+15	+ 9	+12	+ 3	482	+24	+10	+22	+11
16	06.5	53.8	514	694	638	+16	+12	+17	+11	455	+21	+10	+22	+16
17	07.5	62.0	511	666	625	+11	+ 5	+18	+12	428	+19	+ 5	+25	+21
18	08.5	48.5	509	636	612	+ 7	+ 3	+13	+17	399	+18	+ 8	+22	+28
19	09.5	43.9	506	588	592	− 1	− 5	+ 7	+ 5	354	+ 8	− 6	+ 8	+ 9
20	1910.5	18.6	503	546	574	− 6	− 5	− 1	+ 4	314	− 7	− 5	− 3	+ 3
21	11.5	5.7	502	490	550	−15	−12	−11	− 8	262	−27	−19	−23	−20
22	12.5	3.6	498	454	534	−15	−11	−12	− 9	227	−27	−19	−28	−21
23	13.5	*1.4*	505	449	538	+ 8	+12	+ 5	+ 6	226	+ 8	+17	+ 6	+ 6
24	14.5	9.6	488	406	510	0	+ 3	− 3	− 5	179	− 1	+ 5	− 3	− 7
25	15.5	46.0	463	376	484	− 4	− 7	− 7	− 9	142	+ 1	− 7	0	− 4

I*c*, a lag of 3 years was taken. N, N'' and N''' in the various formulae represent, respectively, the mean sun-spot number for the year of observation of G, for 2 years prior, and for 3 years prior. As a measure of the relative value of the quantities computed from the various formulae, the probable error, r, has been computed:

$$r = \pm .6745 \sqrt{\frac{(O-C)^2}{n-m}} \tag{11}$$

where n = number of observations and m = number of unknowns derived by the method of least squares. With these explanations, the derived formulae are now set down from which the computed quantities are obtained for the period 1891-1915 in terms of γ (0.00001 C. G. S.).

$$G_c = 28634.8 - 1.57\,(T-1903.5) - 0.890\,(T-1903.5)^2 \tag{I}$$
$$G_c = 28633.8 - 1.32\,(T-1903.5) - 0.905\,(T-1903.5)^2 + 0.163\,(N \quad -24.4) \tag{Ia}$$
$$G_c = 28644.1 - 1.79\,(T-1903.5) - 0.919\,(T-1903.5)^2 - 0.252\,(N'' -2.7) \tag{Ib}$$
$$G_c = 28645.8 - 1.69\,(T-1903.5) - 0.937\,(T-1903.5)^2 - 0.353\,(N''' -9.5) \tag{Ic}$$
$$F_c = 47500.3 - 19.42\,(T-1903.5) - 0.881\,(T-1903.5)^2 \tag{I'}$$
$$F_c = 46497.8 - 18.80\,(T-1903.5) - 0.918\,(T-1903.5)^2 + 0.406\,(N - 24.4) \tag{I'a}$$
$$F_c = 47506.8 - 19.58\,(T-1903.5) - 0.901\,(T-1903.5)^2 - 0.177\,(N'' -2.7) \tag{I'b}$$
$$F_c = 47511.7 - 19.54\,(T-1903.5) - 0.930\,(T-1903.5)^2 - 0.364\,(N''' -9.5) \tag{I'c}$$

TABLE 4.—*Probable errors for the Kew formulae.*

Formula	Σg^2	r	Formula	Σf^2	r
	γ	γ		γ	γ
I	4028	±9.1	I′	7459	±12.4
Ia	3710	±9.0	I′a	5287	± 9.2
Ib	2979	±8.0	I′b	6946	±12.2
Ic	2088	±6.7	I′c	5357	±10.8

21. The steady improvement in the G-formulae is shown by the continued diminution in the quantities Σg^2 and r, given in Table 4. For formula I*c*, in which a sun-spot term with a lag of 3 years was introduced, Σg^2 has been reduced to about one-half and r to about two-thirds of the respective quantities for formula I in which there was no sun-spot term. *Thus there has been secured an improved representation of the observed quantities, G, by the introduction in the formulae of a term, $s\Delta N$, representing a magnetic effect dependent upon sun-spot periodicity.* The same fact is shown in Table 4 by the values of Σf^2 and r for the F-formulae, though here, however, a somewhat better representation is obtained for the no-lag formula (I′*a*) than for the 3-year-lag formula (I′*c*).

22. *Lag of magnetic curve.* In shifting the magnetic curve so as to fit the sun-spot curve as well as possible, we have the choice of either shifting it backward or forward a number of years. In the former case, the magnetic curve is regarded as lagging behind the sun-spot curve and the value of the coefficient s of the sun-spot term turns out to be negative, which means that increased solar activity is accompanied (or followed) by decreased magnetic intensity; this would accord with the facts previously deduced. On the other hand, if we shift the magnetic curve forward, we assume that the magnetic effect precedes sun-spot activity; in this case the value of s turns out to be positive and we find increased solar activity accompanied (or preceded) by increased magnetic intensity. There are evidences that s may at times be negative and at other times positive, just as we have both decreasing-

intensity and increasing-intensity perturbations. It appears, however, that s is more generally negative than positive, just as magnetic storms are more frequently accompanied by decreasing magnetic intensity than increasing intensity. Accordingly we have given preference at present to the idea that the magnetic curve more generally lags behind solar activity as gauged by sun-spottedness, though the possibility of cases in which magnetic effect may precede sun-spottedness is not excluded—a point which will be further discussed later.

23. The precise *significance of lag of the magnetic curve* by as much as 3 years, for example, is reserved for future examination. It may be related to an effect arising from (a) referred to in paragraph 3, page 3. For Potsdam the lag in the g-curve was found to be about 2 years; at Pola and at Porto Rico magnetic observatories it seemed to be as much as 4 years; at Colaba (Alibag), Honolulu and Cheltenham the lag could be taken as zero, and at Sitka, 3 years. For the 8 observatories considered, the average lag in the g-curve was 2 years and about the same for the f-curve. Of course discontinuities in an observatory series caused, for example, by instrumental differences, may produce an artificial shift in the curve for any particular station. To diminish the effects from such artificial disturbances, our final conclusions are based upon 8 magnetic observatories encircling the globe.

24. From the foregoing it will be evident that we shall not be able at any one station to eliminate wholly from the g-quantities, or from the f-quantities, a magnetic effect dependent upon solar activity, as measured by sun-spottedness. Not only may we have a variable lag during a long series but the coefficient s, itself, may be both variable and even change sign at times. We thus have an explanation for the interesting circumstance revealed by the figures in columns 10 and 13 of Table 3—that although we have used our best formulae there has not been eliminated wholly the sun-spot effect, the residuals still showing a periodicity about that of the sun-spot cycle. It appears, however, that in the average residuals from the 8 observatories, we have obtained finally quantities, either accidental in their run or showing a much reduced periodicity. We have also tried for Kew a formula in which a second-power term depending upon sun-spot periodicity was introduced in addition to the first-power term; the slight improvement resulting was not commensurate, however, with the additional labor involved.

25. *Secular-variation formulae.* Tables 5 and 6 contain a summary of the various formulae established by the Department of Terrestrial Magnetism for the purposes of the present investigation, as well as for others. With the explanations given in para-

TABLE 5.—*Secular-variation formulae for G.*

No.	Obs'tory	Series	Epoch	Lag	G′+x	y	z	s	N_0	r
				Yrs.	γ	γ	γ	γ		γ
I	Kew	1891–1915	1903.5	....	28634.8	− 1.57	−0.890	....	....	±9.1
I*a*		1891–1915	1903.5	0	28633.8	− 1.32	−0.905	+0.163	24.4	±9.0
I*b*		1891–1915	1903.5	2	28644.1	− 1.79	−0.919	−0.252	2.7	±8.0
I*c*		1891–1915	1903.5	3	28645.8	− 1.69	−0.937	−0.353	9.5	±6.7
I*d*		1902–1915	1909.5	....	28594.5	−13.89	−0.740	....	....	±5.5
II	Potsdam	1891–1911	1901.0	....	28634.3	+ 4.58	−1.256	....	....	......
II*a*		1894–1916	1905.5	....	28626.7	− 5.18	−1.083	....	....	±7.1
II*b*		1891–1916	1904.0	2	28640.9	− 2.14	−1.118	−0.243	3.8	±5.5
II*c*		1902–1916	1909.5	....	28577.4	−13.91	−0.533	....	....	±2.8
III	Pola	1904–1915	1910.0	....	29413.1	− 9.58	+0.454	....	....	±5.8
III*a*		1904–1915	1910.0	0	29413.2	− 9.43	+0.438	+0.034	31.2	±6.0
III*b*		1904–1915	1910.0	4	29411.4	− 9.07	−0.010	−0.269	58.6	±5.6
IV	Colaba	1888–1905	1887.5	....	38037.5	+10.93	−0.250	....	....	......
IV*a*	Alibag	1904–1915	1910.0	....	37721.0	+10.67	+1.162	....	....	±7.3
IV*b*		1904–1915	1910.0	0	37720.0	+ 9.49	+1.288	−0.268	31.2	±6.8
V	Honolulu	1902–1916	1909.5	....	31579.4	−29.82	−0.726	....	....	±4.9
V*a*		1903–1915	1909.5	....	31580.1	−28.96	−0.804	....	....	±3.3
V*b*		1904–1914	1909.5	....	31580.3	−28.22	−0.825	....	....	±2.2
V*c*		1904–1915	1910.0	....	31567.7	−29.43	−0.963	....	....	±2.9
V*d*		1904–1915	1910.0	0	31567.7	−30.00	−0.900	−0.127	33.1	±2.1
VI	Sitka	1902–1916	1909.5	....	32212.9	−24.14	−0.652	....	....	±7.5
VI*a*		1903–1915	1909.5	....	32210.4	−24.64	−0.392	....	....	±7.1
VI*b*		1904–1916	1910.5	3	32178.8	−26.91	−0.729	−0.374	62.0	±2.8
VII	Cheltenham	1905–1915	1910.5	....	34378.2	−65.58	−3.897	....	....	±6.9
VII*a*		1904–1916	1910.5	....	34374.3	−65.19	−3.336	....	....	±7.8
VII*b*		1904–1916	1910.5	0	34375.2	−65.75	−3.137	−0.219	18.6	±7.7
VIII	Porto Rico	1905–1915	1910.5	....	33529.2	−65.52	−1.957	....	....	±6.2
VIII*a*		1904–1916	1910.5	....	33530.1	−64.85	−2.083	....	....	±6.0
VIII*b*		1904–1916	1910.5	4	33529.3	−64.61	−2.762	−0.426	53.8	±5.3

graphs 19-22, the various entries in the two tables will require no further remark. It will be seen that the formulae apply to 8 selected magnetic observatories, encircling the globe. For other observatories either the data in recent years were not at hand, or the published series required first some scrutiny in order to eliminate instrumental changes, for which full information is not always given in the publications. Even for the present list some revision will be made later because of suspected discontinuities in instrumental standardizations. Formulae II and II′ for Potsdam and IV and IV′ for Colaba are based, respectively, upon those which Schmidt and Mōos had established for the magnetic quantities which enter into our *G* and *F*. Before establishing our formulae

for the Alibag Observatory, India, the published H- and Z-values were referred all to magnetometer No. 7 and dip circle 160; some revisions may be necessary when the final corrections have been received. N_0 is always the sun-spot number counted from,

TABLE 6.—*Secular-variation formulae for F.*

No.	Station	Series	Epoch	Lag	F′+x	y	z	s	N_0	r
				Yrs.	γ	γ	γ	γ		γ
I′	Kew	1891–1915	1903.5	....	47500.3	−19.42	−0.881	....	....	±12.4
I′*a*		1891–1915	1903.5	0	47497.8	−18.80	−0.918	+0.406	24.4	± 9.2
I′*b*		1891–1915	1903.5	2	47506.8	−19.58	−0.901	−0.177	2.7	±12.2
I′*c*		1891–1915	1903.5	3	47511.7	−19.54	−0.930	−0.364	9.5	±10.8
II′	Potsdam	1891–1911	1901.0	....	47055	− 3.4	−1.38	....	....	......
II′*a*		1891–1916	1904.0	....	47023.4	− 9.14	−0.997	....	....	±15.1
II′*b*		1891–1916	1904.0	0	47023.6	− 9.10	−1.002	+0.032	34.5	±15.4
II′*c*		1891–1916	1904.0	2	47029.4	− 9.31	−1.016	−0.170	3.8	±15.1
III′	Pola	1904–1915	1910.0	....	44516.1	−18.28	+1.058	....	....	±10.9
III′*a*		1904–1915	1910.0	4	44513.4	−17.49	+0.337	−0.417	58.6	±10.9
IV′	Colaba	1888–1905	1887.5	....	39844.9	+26.11	+0.017	....	....	......
IV′*a*	Alibag	1904–1915	1910.0	....	40206.2	+39.27	+1.750	....	....	± 8.9
IV′*b*		1904–1915	1910.0	0	40205.0	+37.88	+1.899	−0.316	31.2	± 8.4
V′	Honolulu	1904–1915	1910.0	....	37932.4	−58.29	−1.183	....	....	± 3.7
V′*a*		1904–1915	1910.0	0	37933.1	−57.76	−1.240	+0.120	31.2	± 3.6
V′*b*		1904–1916	1910.5	....	37901.3	−58.76	−0.948	....	....	± 4.7
V′*c*		1904–1916	1910.5	4	37901.2	−58.71	−1.099	−0.095	53.8	± 5.0
VI′	Sitka	1904–1916	1910.5	....	58489.4	−72.38	−0.024	....	....	± 7.3
VI′*a*		1904–1916	1910.5	0	58489.0	−72.12	−0.119	+0.105	18.6	± 7.8
VI′*b*		1904–1916	1910.5	3	58491.4	−72.16	+0.316	+0.204	62.0	± 7.7
VII′	Cheltenham	1904–1916	1910.5	....	59629.3	−92.81	−6.097	....	....	±22.6
VII′*a*		1904–1916	1910.5	0	59630.4	−93.52	−5.844	−0.279	18.6	±23.4
VIII′	Porto Rico	1904–1916	1910.5	....	44739.6	−12.53	+0.516	....	....	±11.2
VIII′*a*		1904–1916	1910.5	0	44738.4	−11.71	+0.226	+0.320	18.6	±10.9
VIII′*b*		1904–1916	1910.5	4	44738.6	−12.24	−0.298	−0.511	53.8	±11.0

taking into account the amount of lag assumed, as stated in the table.

I desire to make acknowledgment here of the efficient aid received in the establishment of the various formulae from Messrs. H. W. Fisk, C. R. Duvall, and C. C. Ennis, all members of the Department of Terrestrial Magnetism.

26. *Discussion of results from the formulae.* Reference has already been made in paragraph 20 to the first curve (Kew) of Fig. 4. The quantities used in drawing the various curves of Fig. 4 will be found in Table 7. The magnetic curves have been plotted for intensity ordinate increasing downward, whereas for the sun-spot curve the numbers increase upward. We have in Table 7 the values of g and f for series of observations at Kew, Potsdam and Bombay, extending over more than 2 sun-spot

cycles. The formulae for deriving the computed values of G and F were those given in Tables 5 and 6, viz.: Nos. I, I′ for Kew; II, II*a* and II′, II′*a* for Potsdam; IV, IV*a* and IV′, IV′*a* for Colaba and Alibag, called together Bombay. The differences *O-C* are given in columns 1, 2, 3, 7, 8, and 9. The *g*-values are found plotted for Kew, Potsdam and Bombay (Colaba-Alibag). Kew, as already pointed out in paragraph 20, exhibits a lag of 3 years,

Table 7.—*Differences between observed values of G and F and those derived from formulae without sun-spot term.* (*Long series.*)

No.	Date	Sun-spot Nos. SN	$g=G$ (Obs'd-Comp'd)						$f=F$ (Obs'd-Comp'd					
			1 Kew	2 Pot.	3 Bom.	4 (Kew)	5 (Pot.)	6 Mean	7 Kew	8 Pot.	9 Bom.	10 (Kew)	11 (Pot.)	12 Mean
			γ	γ	γ	γ	γ	γ	γ	γ	γ	γ	γ	γ
1	1888.5	6.8	....	....	+ 2	+27	....	[+14]	....	....	− 2	+26	....	[+12]
2	89.5	*6.5*	....	....	+ 9	+ 9	+14	+11	....	....	+17	+13	−43	− 4
3	90.5	7.1	....	....	+ 9	+ 3	+ 3	+ 5	....	....	+16	+ 3	−18	0
4	91.5	35.6	+27	+14	− 3	−11	+ 2	− 4	+26	−43	+ 3	− 8	+21	+ 5
5	92.5	73.0	+ 9	+ 3	−26	−12	− 7	−15	+13	−18	−23	− 6	+ 4	− 8
6	93.5	**84.9**	+ 3	+ 2	−17	−13	−13	−14	+ 3	+21	−25	− 8	− 3	−12
7	94.5	78.0	−11	− 7	−30	−15	− 7	−17	− 8	+ 4	−40	−19	+ 5	−18
8	95.5	64.0	−12	−13	− 8	−16	− 4	− 9	− 6	− 3	−13	−17	+ 6	− 8
9	96.5	41.8	−13	− 7	+10	−18	+ 2	− 2	− 8	+ 5	+11	−28	+20	+ 1
10	97.5	26.2	−15	− 4	+14	− 6	+ 2	+ 3	−19	+ 6	+ 6	−18	+15	+ 1
11	98.5	26.7	−16	+ 2	+ 4	− 5	+14	+ 4	−17	+20	− 4	−19	+31	+ 3
12	99.5	12.1	−18	+ 2	+12	+11	+17	+13	−28	+15	+ 8	+11	+32	+17
13	1900.5	9.5	− 6	+14	+17	+12	+10	+13	−18	+31	+19	+12	+ 7	+13
14	01.5	*2.7*	− 5	+17	+21	+20	+ 4	+15	−19	+32	+26	+28	− 3	+17
15	02.5	5.0	+11	+10	+13	+15	+ 6	+11	+11	+ 7	+17	+24	+ 3	+15
16	03.5	24.4	+12	+ 4	+ 2	+16	+ 2	+ 7	+12	− 3	+ 3	+21	0	+ 8
17	04.5	42.0	+20	+ 6	− 8	+11	− 1	+ 1	+28	+ 3	−11	+19	−12	− 1
18	05.5	**63.5**	+15	+ 2	− 8	+ 7	− 5	− 2	+24	0	− 9	+18	−13	− 1
19	06.5	53.8	+16	− 1	+ 9	− 1	−13	− 2	+21	−12	+11	+ 8	−20	0
20	07.5	62.0	+11	− 5	+ 2	− 6	−16	− 7	+19	−13	+ 3	− 7	−23	− 9
21	08.5	48.5	+ 7	−13	− 1	−15	−16	−11	+18	−20	− 3	−27	−29	−20
22	09.5	43.9	− 1	−16	−13	−15	−13	−14	+ 8	−23	−17	−27	−27	−24
23	10.5	18.6	− 6	−16	−14	+ 8	− 9	− 5	− 7	−29	−18	+ 8	−20	−10
24	11.5	5.7	−15	−13	− 1	0	− 4	− 2	−27	−27	0	− 1	−11	− 4
25	12.5	3.6	−15	− 9	+13	− 4	+ 3	+ 4	−27	−20	+15	+ 1	+ 6	+ 7
26	13.5	*1.4*	+ 8	− 4	+13	....	+ 6	[+10]	+ 8	−11	+14	....	+22	[+18]
27	14.5	9.6	0	+ 3	+ 7	....	+17	[+12]	− 1	+ 6	+ 7	....	+48	[+28]
28	15.5	46.0	− 4	+ 6	−15	....	....	[−15]	+ 1	+22	−18	....	....	[−18]
29	16.5	[70]	....	+17	....	....	....	......	....	+48	....	....	....	......

Potsdam a lag of 2 years, whereas the Bombay-Colaba series shows practically no lag. The curves unite in exhibiting considerable lag with respect to the sun-spot maximum of 1905 and 1907; however, excepting Potsdam, they show a trough coinciding very well in time with the sun-spot minimum of 1913. The value

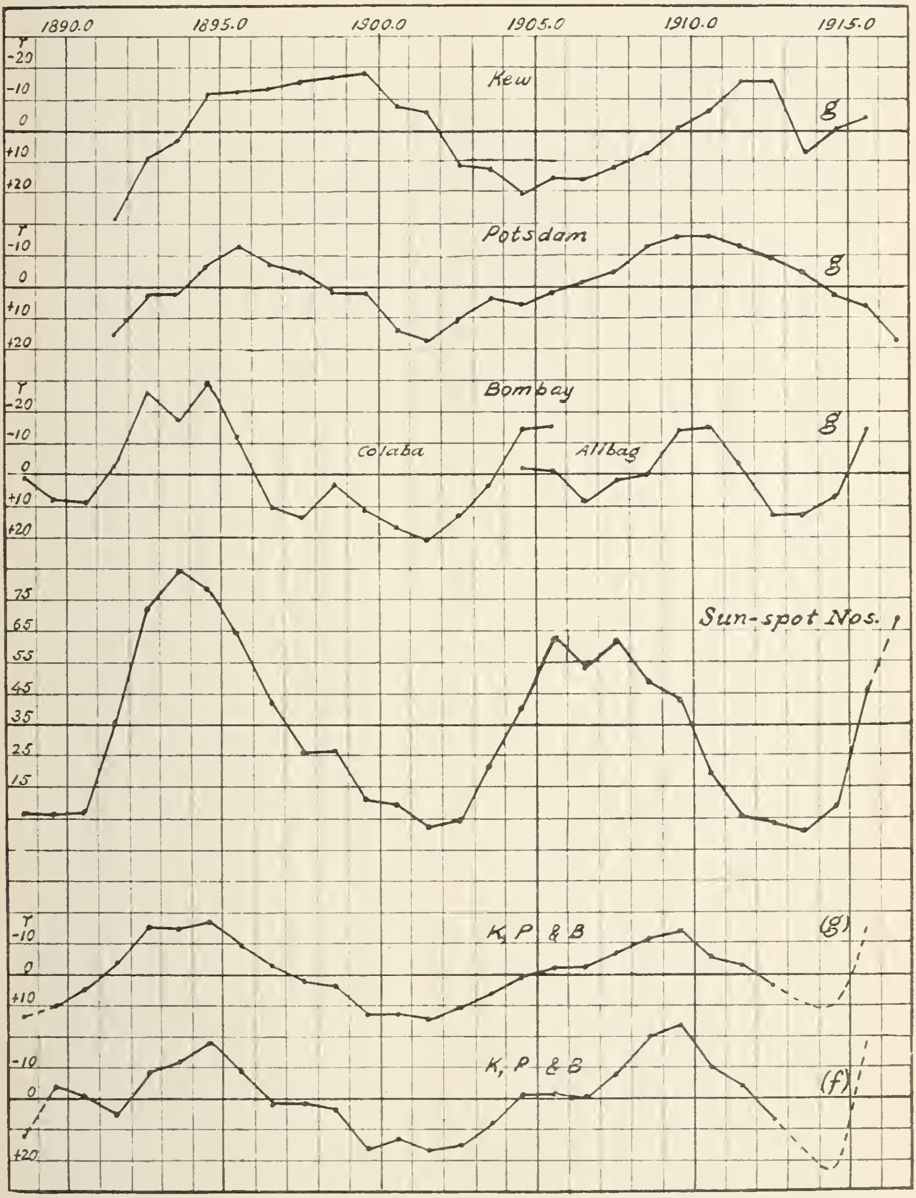

FIG. 4.—Curves Showing the g- and f- effects at Kew, Potsdam and Bombay, 1888-1916.

70 as the sun-spot number for 1916 is a provisional one; it is based upon such sun-spot data as were readily at hand.

Taking a lag of 3 years for Kew, 2 years for Potsdam, and none for Bombay, the quantities in columns 4 and 5 were obtained. Column 6 contains the means of the quantities in columns 3, 4 and 5; these combined results are designated as the K, P and B g-curve. The agreement of the latter curve with the SN-curve, may be regarded as very satisfactory excepting as regards the delayed crest which should have occurred about 1905-1907, instead of in 1909.

An inspection of the curves for Kew, Potsdam and Bombay would indicate that the lag is more pronounced generally at times of sun-spot maxima than at times of sun-spot minima. This is perhaps just what one ought to expect; for at times of sun-spot maxima occur the severest and most continued magnetic storms, whose general effect is to *diminish* the Earth's intensity of magnetization for some period after their cessation, the cumulative diminishing effects thus causing a lag in the magnetic curve at these times.

The K, P and B f-curve was derived in a manner similar to that for the combined g-curve. The shoved-back values of f for Kew and Potsdam are given in columns 10 and 11, and the mean results for columns 9, 10 and 11, will be found in column 12. The f-curve exhibits practically the same features as the g-curve, though it shows more irregularities, because of the fact that in it enter more of the uncertainties in the observed values of inclination, or of vertical intensity, than in the g-curve. In the g-values we have entering only $\frac{1}{4}\ \frac{Z}{G}\ dZ$, whereas in the f-values we have $\frac{Z}{F}\ dZ$ (see formulae 7 and 8), a quantity 2 to 4 times the former.

An inspection of the curves in Fig. 4 will hardly fail to convince one that the absolute magnetic state of the Earth at any moment is dependent upon solar conditions as revealed by sun-spottedness. While the magnetic curves may not always truly synchronize with corresponding features in the sun-spot curve, there is shown an undoubted periodicity approximating the sun-spot cycle. In general, increased sun-spottedness is accompanied, or followed, by decreased intensity of magnetization of the Earth.

(*To be Continued.*)

PRELIMINARY RESULTS OF OCEAN MAGNETIC OBSERVATIONS ON THE CARNEGIE FROM BUENOS AIRES TO TALCAHUANO, DECEMBER 1917—JANUARY 1918.[1]

By H. M. W. Edmonds, Commanding the *Carnegie*.

Observers: H. M. W. Edmonds, A. D. Power, B. Jones, L. L. Tanguy, J. M. McFadden, and W. E. Scott.

Date	Latitude	Long. East of Gr.	Carnegie Values			Chart Differences[2]					
						Decl'n and Incl'n			Hor. Int.[3]		
			Decl'n	Incl'n	Hor. Int.	Brit.	Ger.	U.S.	Brit.	Ger.	U.S.
1917	° ′	° ′	°	°	c.g.s.	°	°	°			
Dec. 6	35 17S	303 19	3.7E	.....	....	0.1E	0.1E	0.3E	...	...	...
6	35 17S	303 34	3.5E	.....	....	0.2E	0.1E	0.4E	...	...	...
7	35 43S	304 05	3.2E	.....	....	0.2E	0.3E	0.2E	...	...	...
7	35 53S	304 10	.....	29.6S	.244	0.3N	0.6S	....	−7	−6	−12
7	36 15S	304 21	3.0E	.....	....	0.0	0.1W	0.0	...	...	...
8	37 31S	304 59	2.9E	.....	....	0.1W	0.2W	0.0	...	...	...
8	38 02S	305 03	.....	31.5S	.244	0.8N	0.3S	....	−8	−8	−13
8	38 20S	305 04	3.1E	.....	....	0.2W	0.1W	0.0	...	...	...
9	39 07S	304 45	3.6E	.....	....	0.3W	0.3W	0.1W	...	...	...
9	39 15S	304 53	.....	32.9S	.245	0.8N	0.1S	....	−8	−8	−13
9	39 04S	304 38	3.7E	.....	....	0.3W	0.1W	0.4W	...	...	...
10	38 53S	303 33	4.5E	.....	....	0.3W	0.1E	0.2W	...	...	...
10	39 00S	302 57	.....	32.7S	.248	1.0N	0.3N	....	−7	−7	−12
10	39 01S	302 55	5.2E	.....	....	0.2W	0.3E	0.1W	...	...	...
11	39 48S	302 32	5.6E	.....	....	0.4W	0.0	0.3W	...	...	...
11	40 06S	302 21	.....	34.1S	.248	0.9N	0.3N	....	−8	−9	−13
11	40 18S	302 10	6.2E	.....	....	0.3W	0.5E	0.1W	...	...	...
12	41 18S	301 13	7.3E	.....	....	0.1W	0.2E	0.1E	...	...	...
12	42 15S	300 17	.....	36.9S	.252	1.0N	0.3N	....	−9	−10	−14
12	42 42S	299 35	8.9E	.....	....	0.0	0.2E	0.0	...	...	...
13	43 27S	298 53	9.6E	.....	....	0.0	0.3E	0.0	...	...	...
13	43 22S	299 04	.....	37.8S	.256	1.6N	1.0N	....	−8	−9	−12
13	43 16S	298 58	9.6E	.....	....	0.1E	0.4E	0.2E	...	...	...
14	43 04S	298 44	9.6E	.....	....	0.0	0.2E	0.0	...	...	...
14	43 04S	298 54	.....	37.6S	.256	1.7N	1.1N	....	−8	−8	−12
14	43 00S	298 54	9.6E	.....	....	0.1E	0.4E	0.1E	...	...	...
15	43 42S	298 12	10.2E	.....	....	0.0	0.3E	0.1E	...	...	...
15	44 54S	297 15	.....	40.0S	.259	1.1N	1.0N	....	−10	−9	−12
15	45 31S	296 47	11.8E	.....	....	0.1E	0.3E	0.4E	...	...	...
16	46 50S	296 49	12.0E	.....	....	0.1W	0.4E	0.2E	...	...	...
16	47 42S	296 55	.....	42.8S	.261	1.0N	0.9N	....	−11	−11	−12
16	47 55S	296 51	12.7E	.....	....	0.3E	0.8E	0.6E	...	...	...
17	49 00S	296 52	12.6E	.....	....	0.2W	0.4E	0.2E	...	...	...
17	50 06S	297 32	.....	45.0S	.265	0.9N	1.0N	....	−7	−10	−8
17	50 30S	297 45	12.5E	.....	....	0.2W	0.3E	0.1E	...	...	...
18	51 04S	297 51	12.4E	.....	....	0.3W	0.0	0.1W	...	...	...
18	51 38S	297 56	.....	46.8S	.266	0.4N	0.5N	....	−11	−11	−7
18	51 56S	298 13	12.4E	.....	....	0.3W	0.0	0.1W	...	...	...
19	52 45S	299 19	11.9E	.....	....	0.4W	0.2W	0.1W	...	...	...
19	53 15S	300 17	.....	47.7S	.263	0.5N	0.8N	....	−8	−13	−8
19	53 25S	300 52	11.2E	.....	....	0.3W	0.1W	0.1E	...	...	...
20	53 14S	300 33	11.0E	.....	....	0.6W	0.5W	0.3W	...	...	...
20	53 08S	300 12	.....	47.4S	.264	0.7N	1.0N	....	−7	−12	−7
20	53 09S	299 38	12.0E	.....	....	0.2W	0.0	0.1E	...	...	...

[1] For previous table, see *Terr. Mag.*, v. 22, pp. 139-144.

[2] Charts used for comparison: U. S. Hydrographic Office Chart No. 2406 for 1915 and No. 1701 for 1900; British Admiralty Charts No. 2598 for 1912, Nos. 3598 and 3603 for 1907; Reichs-Marine-Amt Charts Tit. XIV, No. 2 for 1910, Tit. XIV, Nos. 2a and 2b for 1905. The chart differences are obtained by subtracting corrected chart values, derived as explained in previous sentence, from the observed *Carnegie* values. The letter *E* signifies that the chart value for east declination is smaller, or the chart value for west declination larger, than the *Carnegie* value; *W* signifies the reverse. The letter *N* signifies that the derived chart value for northerly inclination is smaller, or for southerly inclination larger, than the *Carnegie* value; *S* signifies the reverse. The plus sign signifies that the derived chart value for horizontal intensity is smaller than the *Carnegie* value, the minus sign meaning, of course, the reverse.

[3] Expressed in units of third decimal c. g. s.

Date	Latitude	Long. East of Gr.	Carnegie Values			Chart Differences[2]					
						Decl'n and Incl'n			Hor. Int.[3]		
			Decl'n	Incl'n	Hor. Int.	Brit.	Ger.	U.S.	Brit.	Ger.	U.S.
1917	° ′	° ′	°	°	c.g.s.	°	°	°			
Dec. 21	53 30S	299 38	11.9E	.....	....	0.4W	0.2W	0.2W	...	...	...
21	53 34S	299 30	.....	48.3S	.263	0.3N	0.8N	....	−8	−14	−8
21	53 45S	299 05	12.6E	.....	....	0.1W	0.2E	0.2E	...	...	...
22	55 11S	296 45	.....	50.1S	.266	0.7N	0.9N	.....	−7	−14	−7
23	55 56S	295 21	15.3E	.....	....	0.3W	0.1E	0.2W	...	...	...
23	56 13S	295 46	.....	51.3S	.266	0.7N	1.0N	....	−7	−14	−7
23	56 18S	295 50	15.3E	.....	....	0.2W	0.2E	0.1W	...	...	...
24	56 54S	294 49	16.3E	.....	....	0.1E	0.3E	0.1E	...	...	...
24	57 41S	291 46	.....	53.7S	.266	0.7N	0.6N	....	−7	−12	−8
24	58 00S	290 59	18.5E	.....	....	0.2W	0.2W	0.5W	...	...	...
25	58 29S	289 16	20.4E	.....	....	0.5E	0.7E	0.3E	...	...	...
25	58 56S	288 06	.....	55.3S	.264	1.4N	0.9N	....	−10	−8	−10
25	58 57S	287 46	20.8E	.....	....	0.1W	0.0	0.3W	...	...	...
26	58 33S	286 14	22.1E	.....	....	0.6E	0.6E	0.3E	...	...	...
26	58 11S	285 46	.....	55.4S	.264	1.3N	0.8N	....	−11	−8	−11
27	57 32S	286 28	21.6E	.....	....	0.6E	0.6E	0.4E	...	...	...
27	57 44S	286 16	.....	54.7S	.266	1.3N	1.0N	....	−9	−8	−10
27	57 52S	285 55	21 6E	.....	....	0.1E	0.1E	0.2W	...	...	...
28	58 14S	285 22	22.1E	.....	....	0.3E	0.3E	0.0	...	...	...
28	58 38S	284 39	.....	56.0S	.267	1.4N	0.8N	0.0	−8	−4	−8
29	59 08S	284 21	22.5E	.....	....	0.2W	0.3W	0.6W	...	...	...
29	59 08S	284 13	.....	56.4S	.265	1.7N	1.0N	....	−9	−4	−9
29	59 06S	283 40	23 1E	.....	....	0.1E	0.1W	0.3W	...	...	...
30	58 45S	282 04	23.6E	.....	....	0.1W	0.2W	0.6W	...	...	...
30	58 25S	280 41	.....	56.9S	.264	1.7N	0.7N	....	−12	−4	−10
30	58 17S	280 30	24.3E	.....	....	0.0	0.1W	0.4W	...	...	...
31	55 30S	279 37	.....	54.6S	.271	1.2N	1.3N	....	−7	−1	−7
1918											
Jan. 1	53 06S	279 44	23.2E	.....	....	0.6E	0.4E	0.5E	...	...	...
1	52 12S	280 09	.....	51.8S	.272	0.1N	1.2N	....	−8	−5	−9
1	51 44S	280 24	22.2E	.....	....	0.2E	0.2E	0.3E	...	...	...
2	52 15S	278 54	.....	52.2S	.271	0.1N	1.2N	....	−9	−5	−9
2	52 23S	278 49	23.2E	.....	....	0.4E	0.2E	0.3E	...	...	...
3	52 27S	278 56	23.1E	.....	....	0.3E	0.3E	0.2E	...	...	...
3	51 50S	279 14	.....	51.6S	.272	0.1N	1.4N	....	−8	−4	−9
3	51 35S	279 24	22.4E	.....	....	0.2E	0.1E	0.1E	...	...	...
4	50 45S	279 52	22.6E	.....	....	0.8E	0.7E	0.8E	...	...	...
4	50 17S	279 53	.....	50.0S	.273	0.3S	1.6N	....	−7	−6	−8
4	49 55S	279 49	21.6E	.....	....	0.0	0.0	0.1E	...	...	...
5	48 29S	279 34	22.0E	.....	....	0.8E	0.8E	0.8E	...	...	...
5	47 15S	279 23	.....	47.7S	.273	1.1S	1.7N	....	−7	−8	−9
5	46 48S	279 26	21.5E	.....	....	0.7E	0.8E	0.7E	...	...	...
6	45 18S	280 04	20.3E	.....	....	0.2E	0.2E	0.1E	...	...	...
6	44 26S	280 28	.....	44.9S	.273	1.3S	1.9N	....	−5	−10	−10
7	43 00S	281 16	19.4E	.....	....	0.3E	0.5E	0.2E	...	...	...
7	42 43S	281 26	.....	42.8S	.272	0.8S	2.0N	....	−5	−10	−10
7	42 37S	281 31	19.7E	.....	....	0.7E	1.2E	0.6E	...	...	...
8	41 57S	281 59	18.6E	.....	....	0.0	0.4E	0.2W	...	...	...
8	41 22S	282 24	.....	41.4S	.271	0.8S	1.8N	....	−4	−10	−11
8	41 05S	282 36	18.5E	.....	....	0.4E	0.8E	0.2E	...	...	...
9	39 09S	283 35	.....	38.8S	.268	0.8S	1.8N	....	−5	−10	−13
9	38 57S	283 44	17.5E	.....	....	0.4E	0.9E	0.3W	...	...	...
10	37 21S	285 28	15.9E	.....	....	0.0	0.4E	0.5W	...	...	...
10	36 45S	286 28	.....	35.1S	.265	0.5S	1.7N	....	−5	−7	−13
10	36 34S	286 44	15.3E	.....	....	0.3E	0.5E	0.1W	...	...	...

THE INFLUENCE OF CHANGES IN LUNAR DISTANCE UPON THE LUNAR-DIURNAL MAGNETIC VARIATION.

By S. Chapman

In a recent paper in the "Philosophical Transactions" (A. 215, p. 161, 1915) I discussed the influence of changes in the Moon's distance upon the amplitude and phase of the semidiurnal component of the lunar-diurnal magnetic variation. It appeared that the amplitude (c_2) increases from apogee to perigee by an amount comparable with, though perhaps rather less than, the increase in the tidal force of the Moon (*i. e.*, nearly proportional to distance $^{-3}$). During the same time the phase angle (θ_2) advances through about 20° or 25°. The former result was regarded as supporting the hypothesis that the lunar-diurnal magnetic variation is a consequence of a lunar tide in the atmosphere. The phase effect was left unexplained: in consequence of further study, of this and of the atmospheric tide, I hope to return, before very long, to the discussion of this point. Meanwhile I have thought it may be of interest to describe certain additional data[1] which have been obtained since the former paper was written.

These relate to the component of frequency 3 $c_3 \sin(3t+\theta_3)$ in the lunar-diurnal magnetic variation. It may be recalled that the latter has components of all frequencies, $\Sigma\, c_n \sin(nt+\theta_n)$ in the lunar day, although the tidal motion from which it originates is purely semidiurnal. This is because a daily variation of electric conductivity in the upper atmosphere (where the magnetic variations are produced) is also involved. Now this has diurnal components of all frequencies, and these components depend on *solar* time, in consequence of which the non-semidiurnal terms in the lunar magnetic variation slowly change in phase angle (θ_n ; $n \neq 2$) throughout the synodic month. Nevertheless, when this has been allowed for, they would be expected to show the same change of amplitude, and some such change of phase, as is produced in c_2 and θ_2 through the variation in the Moon's distance. I therefore decided to examine one non-semidiurnal component to test this point.

[1] I have pleasure in acknowledging the computing assistance rendered available to me in this work by the Government Grant Committee of the Royal Society.

The third harmonic was the one chosen for investigation. The 24-hour term seemed more affected by accidental error than the 8-hour term, while the components of higher frequency are of smaller amplitude. The difficulty which has, in any case, to be faced is that all the terms in the lunar magnetic variation are very small, so that the accidental error involved in determining them may mask such changes as are now under discussion. The results to be described are derived from the hourly values of the magnetic elements at the observatories of Pavlovsk, Pola, Zikawei, and Manila, in each case for seven magnetically "quiet" or "moderate" years. The year was subdivided into three seasons in the usual way. Only those elements (and for those seasons and observatories) for which c_3 exceeded 0.5γ (5×10^{-6} C. G. S.) were chosen for this discussion, in order not to waste time on computations which were not likely to show a change of c_3 and θ_3 comparable with the accidental error of determination.

In dealing with the semidiurnal term, for which the phase angle θ_2 is constant as far as regards the synodic month, the lunar-distance effect was determined from the mean of short periods of three or four days centered at apogee and perigee, and also from half lunations similarly disposed. The present results for c_3 and θ_3 are deduced from the short periods only, in order to avoid the additional trouble involved in correcting the synodic change in θ_3 during the half lunations. The results from the short periods should show the maximum effect, though they are also more liable to accidental error than those derived from a larger amount of observed material.

The ratios c_P/c_A of the amplitudes so found at perigee and apogee, and the phase differences $\theta_P - \theta_A$, are given in Table 1. In Table 2 are given the corresponding values of α and β, where

$$\begin{array}{llll} \alpha = a, & \beta = b & \text{if } a, b \text{ are both positive,} \\ \alpha = -a, & \beta = -b & \text{if } a, b \text{ are both negative,} \\ \alpha = b, & \beta = -a & \text{if } a \text{ is negative and } b \text{ positive,} \\ \alpha = -b, & \beta = a & \text{if } a \text{ is positive and } b \text{ negative,} \end{array}$$

and a, b are the Fourier coefficients in the expression

$$a_3 \cos 3t + b_3 \sin 3t,$$

which is equivalent to

$$c_3 \sin (3t + \theta_3).$$

TABLE 1.

Observatory	Element	Season	c_P/c_A	$\theta_P - \theta_A$
				°
Pavlovsk	H.F.	Summer	0.74	9
Pola	H.F.	Summer	1.13	2
"	H.F.	Equinox	1.23	42
Zikawei	Dec.	Summer	1.53	17
"	Dec.	Equinox	0.59	3
Manila	H.F.	Winter	1.77	11
"	Dec.	Summer	1.41	34
"	Dec.	Winter	0.70	46
"	Dec.	Equinox	0.53	36
"	V.F.	Equinox	0.98	10
"				

TABLE 2.

Observatory	Element	Season	Fourier coefficients: unit 10^{-7}C.G.S.			
			a_P	a_A	β_P	β_A
Pavlovsk	H.F.	Summer	76	98	14	34
Pola	H.F.	Summer	80	68	87	79
"	H.F.	Equinox	62	4	60	69
Zikawei	Dec.	Summer	63	13	137	98
"	Dec.	Equinox	18	20	67	99
Manila	H.F.	Winter	68	32	54	38
"	Dec.	Summer	80	17	75	75
"	Dec.	Winter	51	42	8	61
"	Dec.	Equinox	38	16	38	99
"	V.F.	Equinox	58	58	4	15
		Mean	59	37	54	67

The mean of the a's and β's should show the effect on the amplitudes and phases in some ways better than in Table 1, since the individual results receive proper weight according to their magnitude in force units. The values of c_P, θ_P, c_A, θ_A obtained from Table 2 are respectively:

$$81,\ 48°;\ 76,\ 29°,$$

so that

$$c_P/c_A = 1.06;\ \theta_P - \theta_A = +19°.$$

These values agree very well with the mean of those in Table 1, viz.:

$$c_P/c_A = 1.06;\ \theta_P - \theta_A = +21°;$$

it may be noticed that not one of the individual values of $\theta_P - \theta_A$ in Table 1 is negative.

The corresponding values obtained for the semidiurnal component $c_2 \sin(2t + \theta_2)$, from the short periods, were (*l. c.*):

$$c_P / c_A = 1.36; \quad \theta_P - \theta_A = +25°.$$

These were reduced in the manner of Table 1; if re-computed after the manner of Table 2, the following values are arrived at:

$$c_P / c_A = 1.31; \quad \theta_P - \theta_A = +25°.$$

I should have expected the amplitude ratio to be the same, or nearly so, for c_2 and c_3; the difference is, however, rather large even when the considerable possibility of accidental error is considered. The probable error of c_P / c_A as calculated from Table 1 is 0.10. The ratio of the tidal forces during the short periods centered at perigee and apogee is 1.38. The ratio for the half lunations is 1.23, while the corresponding ratio c_P / c_A, determined from the semidiurnal component of the magnetic variation, was 1.14; $\theta_P - \theta_A$ was determined from the half lunations as equal to $+9°$. The advance of phase angle in θ_2 and θ_3, and presumably in all the other components, from apogee to perigee, seems indubitably substantiated though its amount cannot be regarded as known very exactly. The increase of amplitude also appears likely to be common to all components, as we should expect; and its amount seems to be less than the increase in tide-producing force.

ROYAL OBSERVATORY, GREENWICH.

THE MAGNETOGRAPH RECORDS AT THEODOSIA, CRIMEA, DURING THE TOTAL SOLAR ECLIPSE OF AUGUST 21, 1914.

BY L. PALAZZO.

On the occasion of the solar eclipse of August 21, 1914, a party of Italian scientists, of which the writer was a member, was organized by the Director-astronomer Prof. Ricco of Catania, and went to Theodosia, Crimea, in the belt of totality. Astronomical, spectroscopic and photographic observations on the celestial phenomenon were to be made, as well as by the writer various geophysical investigations allied with the occurrence of the eclipse. The scheme of work was planned to embrace pyrheliometric, meteorological and magnetic observations, measures of the penetrating radiation, and records of temperature on the soil surface. But the principal work proposed was properly the magnetic one, viz., that of registering the variations of the three magnetic elements during the eclipse.

The station occupied by the Italian expedition was a country-house in a garden not far from town, which was free from the traffic of electric cars. The geographic position of our station was assumed to be: latitude, 45° 02′ 03″ N, longitude, 35° 22′ 30″ E or $2^h\ 21^m\ 30^s$ E of Gr.

In a suitable ground-room a photographic self-recording apparatus (built according to special directions given by the writer) was installed in conjunction with the three Mascart variometers. The source of light for the photographic registering was an atmospheric acetylene burner. The sensitiveness, i. e., the scale values of the variation instruments were as follows: for the declinometer 0′.99, for the bifilar and balance 4.28 and 6.75γ respectively, per 1 *mm* of ordinate measured on the photographic sheet, which was running at a rate of nearly 24 *mm* per hour. The diurnal range of temperature in the magnetograph room was so slight that it seemed unnecessary to apply any correction for change in temperature.

Our magnetograph was working day and night from August 16 to 28, and thus we could determine the average solar-diurnal course of the three magnetic elements D, H, Z on several days immediately before and after, as well as on the very day of eclipse. This average daily change, assumed as normal, is represented by the figures of the following table, which gives, for each magnetic element, the average departures from the daily mean value at the half hour between each of the 24 hours. A + sign means a motion of north end of the magnet toward the east for D, for H and Z it means that the values of these elements are greater at the time than the mean values for the day. The intensity values are expressed in terms of $\gamma = 0.00001$ C. G. S. unit.

Table 1.—*Average magnetic diurnal variations as observed at Theodosia, in the second half of August 1914.*

Theod. M. T.	h m 0 30	h m 1 30	h m 2 30	h m 3 30	h m 4 30	h m 5 30	h m 6 30	h m 7 30	h m 8 30	h m 9 30	h m 10 30	h m 11 30
	′	′	′	′	′	′	′	′	′	′	′	′
D	+0.43	+0.11	+0.86	+0.64	+0.87	+1.98	+3.12	+3.94	+3.82	+2.27	−0.09	−2.58
	γ	γ	γ	γ	γ	γ	γ	γ	γ	γ	γ	γ
H	+6.4	+8.0	+8.4	+8.3	+6.0	+8.6	+6.8	−0.1	−14.2	−22.4	−23.5	−16.5
Z	−0.2	+0.6	+1.0	+3.7	+4.2	+8.9	+9.2	+9.1	+ 6.4	+ 4.8	− 0.2	− 3.3

Theod. M. T.	h m 12 30	h m 13 30	h m 14 30	h m 15 30	h m 16 30	h m 17 30	h m 18 30	h m 19 30	h m 20 30	h m 21 30	h m 22 30	h m 23 30
	′	′	′	′	′	′	′	′	′	′	′	′
D	−4.68	−5.28	−4.36	−2.79	−0.71	+0.38	+0.11	+0.21	+0.17	+0.47	+0.71	+0.61
	γ	γ	γ	γ	γ	γ	γ	γ	γ	γ	γ	γ
H	−7.9	−2.1	+2.8	+1.4	−6.2	−6.0	−3.7	+0.5	+7.6	+11.0	+14.0	+12.7
Z	−8.2	−9.8	−9.4	−8.8	−6.9	−4.6	−4.0	−2.0	+0.9	+1.6	+2.6	+4.2

For the day of the eclipse the scaling of the registered magnetic traces was done with the greatest accuracy, and the ordinates were taken at intervals of 2½ minutes, from 12^h to 18^h according to local mean time. At Theodosia the eclipse began at $14^h\ 09^m\ 25^s$ and ended at $16^h\ 25^m\ 39^s$, the middle of totality taking place at $15^h\ 20^m\ 12^s$; the corresponding instants of Greenwich meantime being respectively: $11^h\ 47^m\ 55^s$, $14^h\ 4^m\ 9^s$, $12^h\ 58^m\ 42^s$.

A minute scrutiny of the curves, followed by an exhaustive discussion of the results obtained, is given in a full account, with graphical plates and some diagrams about to be published in issues of "*Memorie della Società degli Spettroscopisti Italiani,*" from April to October 1917.

In the above-mentioned report the writer concludes that a small magnetic effect referable to the eclipse has manifested itself, especially in the declination curve. The principal disturbance occurred almost 6 minutes before totality, and its range may be estimated about $0'.85$ (the north end of the declination needle being deflected towards east by a disturbing force of $= 5.7\gamma$).

We present below a copy of the table which exhibits the five-minute mean results of our magnetic records at Theodosia, viz., the departures, in the daily course of *D*, *H*, *Z*, from the mean value of the eclipse day, August 21, for every fifth minute during the time interval 10^h to 17^h of Greenwich m. t., each tabular figure

being approximately the average value for the five-minute period of which the tabular time is in the middle. This table is published to enable anyone to compare the magnetic results of Theodosia with similar and simultaneous data sent by other observers. Much of this material has already been published in *Terrestrial Magnetism and Atmospheric Electricity*,[1] but so far only for stations situated outside the path of totality.

TABLE 2.—*Magnetic variations during the hours of the solar eclipse, August 21, 1914.*

G. M. T.		D	H	Z	G. M. T.		D	H	Z	G. M. T.		D	H	Z
h	m	′	γ	γ	h	m	′	γ	γ	h	m	′	γ	γ
10	0	−4.04	− 1.9	− 8.2	11	40	−4.23	+15.7	− 5.3	13	20	−0.67	− 8.3	−5.9
	5	−3.76	− 4.2	−10.1		45	−4.17	+16.2	− 5.3		25	−0.56	− 9.0	−5.1
	10	−3.79	− 4.0	−10.5		50	−4.01	+16.5	− 5.7		30	−0.42	− 9.8	−5.0
	15	−4.03	− 2.0	−10.3		55	−3.64	+15.7	− 6.6		35	−0.38	−10.1	−4.6
	20	−4.23	− 0.8	− 9.9	12	0	−3.39	+14.2	− 7.8		40	−0.29	−10.1	−4.0
	25	−4.18	− 0.7	− 9.0		5	−3.19	+13.1	− 8.4		45	−0.20	− 9.4	−3.1
	30	−4.01	0.0	− 9.4		10	−2.90	+12.9	− 8.9		50	−0.18	− 8.9	−3.0
	35	−3.98	+ 1.0	− 8.7		15	−2.58	+12.6	− 9.0		55	−0.08	− 8.9	−2.2
	40	−3.99	+ 3.0	− 7.9		20	−2.38	+11.7	− 9.0	14	0	−0.01	− 9.0	−1.2
	45	−4.09	+ 4.0	− 7.6		25	−2.28	+ 9.7	− 9.1		5	−0.01	− 8.9	−1.6
	50	−4.20	+ 6.0	− 7.0		30	−2.21	+ 7.9	− 9.2		10	−0.09	− 8.1	−2.0
	55	−4.29	+ 9.0	− 6.2		35	−2.02	+ 5.7	− 9.6		15	−0.20	− 6.9	−1.0
11	0	−4.32	+11.1	− 5.9		40	−1.66	+ 3.0	−10.1		20	−0.32	− 5.2	−0.6
	5	−4.34	+12.2	− 5.5		45	−1.31	+ 0.1	−10.6		25	−0.21	− 5.3	−1.0
	10	−4.33	+12.6	− 5.7		50	−1.09	− 2.8	−10.9		30	+0.03	− 5.2	−1.4
	15	−4.29	+12.8	− 5.0		55	−1.01	− 4.3	−10.9		35	−0.02	− 4.2	−1.9
	20	−4.26	+12.9	− 5.2	13	0	−1.03	− 4.9	−10.1		40	−0.18	− 3.6	−2.9
	25	−4.26	+13.2	− 4.7		5	−1.04	− 6.2	− 9.0		45	−0.13	− 3.2	−3.1
	30	−4.24	+13.5	− 4.4		10	−1.00	− 7.0	− 7.8		50	−0.01	− 3.2	−3.4
	35	−4.22	+14.5	− 6.2		15	−0.82	− 7.7	− 6.7		55	+0.14	− 2.9	−3.9
...	...	...	...	...	...	...	...	...	...	15	0	+0.34	− 2.8	−4.0

The absolute values of the magnetic elements were also determined, with the field-magnetometer and the dip-circle (mounted under a tent in the garden), on August 26 and 27. We found:

$$D = +1^\circ\ 02'.7, \qquad I = +59^\circ\ 28'.5, \qquad H = 23218\gamma;$$

The total intensity and its components are therefore:

$$T = 45712\gamma, \qquad X = +23214\gamma, \qquad Y = +423\gamma, \qquad Z = +39377\gamma.$$

Hence we have also calculated the so-called "local magnetic constant"[2] at Theodosia: G = 0.30442 C. G. S.

All these apply, of course, to the epoch 1914.65.

Rome, October 1917.

[1] Vols. **21**, pp. 9, 57, 145, and **22**, pp. 38 and 182.

[2] *Terr. Mag.* vol. **19**, p. 115.

PROPOSED MAGNETIC AND ALLIED OBSERVATIONS DURING THE TOTAL SOLAR ECLIPSE OF JUNE 8, 1918.

By L. A. Bauer.

Special magnetic and allied observations will be made at various points inside and outside the shadow belt of the coming total solar eclipse, by the Department of Terrestrial Magnetism of the Carnegie Institution of Washington, the Coast and Geodetic Survey, and some other institutions and individuals who have offered their cooperation.

The general scheme of work proposed by the Carnegie Institution Department of Terrestrial Magnetism embraces the following:

1. Simultaneous magnetic observations of any or all of the elements according to the instruments at the observer's disposal, every minute from June 8, 1918, 7 P.M. to 1 A.M. June 9, Greenwich civil mean time, or from June 8, 7^h to 13^h Greenwich astronomical mean time.

(To insure the highest degree of accuracy, the observer should begin work early enough to have everything in complete readiness in proper time. See precautions taken in previous eclipse work as described in the journal *Terrestrial Magnetism*, Vol. V., page 146, and Vol. VII., page 16. *Past experience has shown it to be essential that the same observer make the readings throughout the entire interval.*)

2. At magnetic observatories, all necessary precautions should be taken to insure that the self-recording instruments will be in good operation not only during the proposed interval but also for some time before and after, and eye-readings should be taken in addition wherever it is possible and convenient. (*It is recommended that, in general, the magnetograph be run on the usual speed throughout the interval, and that, if a change in recording speed be made, every precaution possible be taken to guard against instrumental changes likely to affect the continuity of the base line.*)

3. Atmospheric-electric observations should be made to the extent possible with the observer's equipment and personnel at his disposal.

4. Meteorological observations in accordance with the observer's equipment should be made at convenient periods (as short as possible) throughout the interval. It is suggested that, at least, temperature be read every fifth minute (directly after the magnetic reading for that minute).

5. Observers in the belt of totality are requested to take the magnetic reading every thirty seconds during the interval, 10 minutes before and 10 minutes after the time of totality, and to read temperature also every thirty seconds, between the magnetic readings.

It is hoped that full reports will be forwarded as soon as possible for publication in the journal of *Terrestrial Magnetism and Atmospheric Electricity*.

REMARKS REGARDING LEAST-SQUARE FORMULAE.[1]

By M. H. Doolittle.

For intelligent and profitable least-square computation it is necessary that there shall be at least an antecedent working hypothesis, if not an established theory. The method of least squares assumes that within satisfactory limits the irregularities and observer's errors of opposite algebraic signs balance each other. By a least-square computation the computer's discrepancies of opposite algebraic signs may be made to balance each other precisely; and if the preliminary assumption is tenable and the least-square computation is controlled by the adopted standard of regularity, it follows that the computer's discrepancies represent within satisfactory limits the irregularities and observer's errors, and that conclusions may be deduced from those discrepancies with a satisfactory approximation to accuracy. If there is no such standard of regularity at the beginning, nothing better than an inconsequential formula can be expected at the end. Least-square computations are not an exception to the rule of logic that conclusions must not transcend premises. If there is good reason for confidence in the antecedent standard of regularity, there may be good reason for faith in the results, but not otherwise.

If a constant has been observed there must be good reason to believe that efficient precautions have been taken against inadmissible preponderance of positive or negative error. If a variable has been observed (as in a census), the general conditions of the variation must not be assumed as properly represented in any formula that suits a counterfeiter's convenience or caprice. It is imperative that they shall be so far understood that a standard of regularity can be adopted with good reason to believe that the apparent balance of discrepancies will approximately represent a reality.

. . . .

I think it may be safely predicted that a proper gauge of the

[1] Extracts made from the late M. H. Doolittle's letters by his son-in-law, L. A. Bauer. Mr. Doolittle was for many years a computer in the United States Coast and Geodetic Survey, and was universally regarded as one of the leading experts in the application of the method of least squares and in the least-square adjustment of observations; he died in 1913. The letters date about 20 years ago; while they were evoked primarily by discussion with various authors of formulæ for prediction of population, it is believed that the extracts will also be of interest to readers of this Journal, who may have occasion to establish least-square formulæ.—Ed.

stability of general conditions will never be obtained by any method that makes it unnecessary to know or even care to know anything about them.

. . . .

It seems to me evident that the results, for example, of the census enumerations made more than fifty years ago can be of very slight assistance toward an intelligent estimate of the results of future ones. The very great improvements that have been made in the arts of production and transportation and other enormous changes make them irrelevant to problems of the future. I should think it very much more suitable to take into consideration the immigration statistics of the present time. Even where least-square computations are serviceable, I believe it is usually of much greater importance to be able to discriminate in the choice of data between what is worthless and what is valuable.

. . . .

It may be true that no satisfactory theory of the drifting of the Sun-spots has been reached; and it is certainly true that the accepted hypothesis only pushes the explanation farther back; but I think I may safely venture the prediction that progress in science will depend in all future time as it has done in the past on the ability to push explanations farther back in just that way. Inscrutable mystery underlies all existence; and all explanations are limited by the unknowable. Newton's explanation of the planetary motions was unsatisfactory because it furnished no clue to the primary mystery of gravitation. The theory of an attractive force varying inversely as the square of the distance only pushed the explanation farther back; but the relegation of the unsolved mystery to the background left the foreground clear for the stupendous science of modern astronomy. The Method of Working Hypothesis and the Method of Counterfeit Formula have indeed this resemblance—that neither explains everything; but this extent of similarity hardly justifies the assertion that the one "is exactly such a case" as the other.

In regard to the rotations of the Sun-spots, it is said that doubtless the phenomenon is due to a large number of causes acting together. This is indeed very probable. The planetary motions are affected by numerous perturbations, but are almost entirely due to a central force; and it may be that the drifting of the Sun-spots is mainly due to causes so few in number as not to be unmanageable and so predominant that the influence of other causes may be

properly relegated to a residual field. It may be that the general conditions have been studied with such success that there is good reason to believe that the adopted "intricate" formula has a general form capable of expressing them. But it is said, furthermore: "No one pretends that this intricate formula expresses any real law of nature. But it does express the mathematical relation which connects together the observations"—as if there could be only one such mathematical relation. There is an infinite variety of purely mathematical relations that may connect together any numbers. Does not this formula express something more than a fanciful mathematical relation? Is there not good reason to believe that it expresses with a good degree of accuracy a true principle of regularity in a natural phenomenon? If so, I do not consider it necessary to inquire whether it is broad enough or important enough or sufficiently well established to be called a law of nature. It is also said, "This formula is a complicated one when written in its mathematical form, and involves a trigonometrical function of the latitude of the spot raised to a fractional power." This implies that the formula may be written in a more simple form that is not mathematical. If so, it differs in this respect from our formulas for estimating population; for they have no other form whatever.

. . . .

While a geometrical progression can be precisely counterfeited to the extent of four terms and approximately counterfeited for a larger number of terms by an algebraic equation of the third degree, the general condition of a geometrical progression cannot be expressed by an algebraic equation of the third or any other degree.

NOTES

1. *Principal Magnetic Storms Recorded at the Cheltenham Magnetic Observatory.*

Latitude 38 44'.0 N; Longitude 76 50.5'W, or 5^h 07^m 4W of Greenwich. October 1 to December 31, 1917.[1]

Greenwich Mean Time		Range		
Beginning	Ending	Declination	Hor'l Intens.	Vert'l Intens.
h m	h	′	γ	γ
Dec. 16, 9 12	Dec. 17, 4—	51.6	240	174

This above storm was associated with the auroral display in England, noted by Dr. Chree in *Nature* for January 3, 1918.

2. *United States Magnetic Tables and Magnetic Charts for 1915.*[2] This publication by *D. L. Hazard,* Chief of the Division of Terrestrial Magnetism of the Coast and Geodetic Survey, is the second edition of the similar tables and charts for 1905, by *L. A. Bauer,* brought up to the date 1915. Besides the accumulated data of the Coast and Geodetic Survey, those obtained in contiguous regions by other organizations (Carnegie Institution of Washington, Surveys of Canada, Mexico, etc.) were utilized. The extension of the isomagnetic lines over the adjacent water areas depend upon the observations of the C. and G. S. vessels and upon those of the *Galilee* and the *Carnegie* of the Department of Terrestrial Magnetism, altogether 6,120 declination results, 5,517 for inclination and 5,420 for intensity. The average density of distribution of magnetic stations in the United States proper is one declination result per 596 square miles, one inclination result per 640 square miles, and one intensity result per 650 square miles. On the average, then, the magnetic stations are about 25 miles apart.

Pp. 16-94 contain the results of observations at repeat stations; pp. 95-99, the secular change tables; pp. 100-218, observed magnetic elements on land and corresponding values for January 1, 1915; pp. 219-217, results of observations at sea; and pp. 227-256, the magnetic elements and magnetic components for each degree of latitude and longitude, from latitude 19° N to 51° N. No discussion of the data from a theoretical standpoint, is attempted in this valuable publication.

The typographical reproductions of the five appended magnetic charts (declination, inclination, horizontal, vertical, and total intensity) are, in general, excellent.

[1] Communicated by *E. Lester Jones,* Superintendent, Coast and Geodetic Survey, George Hartnell, observer-in-charge.

[2] Special Publication No. 44 of the U. S. Coast and Geodetic Survey, Washington, D. C.

LETTERS TO EDITOR

RESULTS OF OBSERVATIONS OF EARTH CURRENTS MADE AT JERSEY, ENGLAND, 1916-1917.[1]

The results were obtained by making electrical connection, through a galvanometer, between the gas-pipe system of the city of St. Helier, Jersey, and the water system (800 or 900 meters of galvanized iron pipe) of the Observatory St. Louis. The galvanometer used in the observations for the year 1916-1917 was of the moving-coil type and was constructed at the Observatory. The resistance was about 150 ohms. At a distance of 30 cm. from the mirror, a deflection of 1 mm. corresponded to a potential-difference of 0.002 volt between its terminals. An improved galvanometer was installed at the end of September 1917, but this was not used during the period covered by the present observations.

The Observatory grounds are situated on a hill overlooking the city of St. Helier, being about 50 meters above it. The greater part of the gas-pipe system of the city lies to the southeast, south and west of the Observatory, yet some extensions thereof reach back of the Observatory. The territory from which the gas-pipe system is assumed to draw its current is given as 4 square kilometers, while the area of the Observatory's water-pipe system, forming the other electrode, is given as 40,000 square meters. This makes the area of the larger system about 100 times that of the smaller one. The gas-pipe and water-systems are neither interlaced nor parallel, and do not cross each other except where the service pipe of the gas system enters the Observatory grounds. The two terminals, between which the galvanometer was connected, emerge from the soil about 4 meters distant from each other.

It was not found necessary to use *two* extended systems such as those used in the main observations. Observations were also made where one terminal was a pipe system and the other merely a piece of copper, say 1 meter square, or several meters of lead pipe. Variations of voltage were found between either of these small terminals on the one hand and a pipe-system on the other, similar to those observed in the main observations, but the potential differences were 5 or 6 times as large.

It is important that *one* of the two electrodes to such a system as used be of very large area in order to avoid polarization effects, and that the electrodes be not equivalent from the point of view of the contact potential with the moist soil for there would no longer be a difference of po-

[1] Abstract of preliminary communications and letters received Nov. 1917-Feb. 1918. The Author expects to make full publication about the end of 1918. The abstract has been prepared by Dr. S. J. Mauchly of the Department of Terrestrial Magnetism.—Ed.

tential to cause a current. The direction of the current observed depended upon the nature of the electrodes.[2]

The observations extended over one year, September 1916, to August 1917, inclusive, and consisted primarily of measurements of potential-difference and of electric current between the two pipe systems. The smaller (water) system was always found to be negative in reference to the larger (gas) system, the mean potential-difference for the 101 "calm" days of the year being 0.079 volt. The mean current for the same days was 1.967 milliamperes.

If the 101 days are resolved into four seasons, the mean potential-differences are as follows: Winter, 0.089 volt (26 days); spring, 0.081 volt (21 days); summer, 0.070 volt (29 days); autumn, 0.075 volt (25 days).

Diurnal variation of the potential-difference. (*Mean of 101 calm days.*)
(The values of P.D. are expressed in millivolts.)

Hour	P.D.	Hour	P.D.	Hour	P.D.	Hour	P.D.	Hour	P.D.
0	+3.2	5	−3.8	10	+1.6	15	+1.2	20	−1.9
1	+2.8	6	−4.7	11	+3.7	16	−1.0	21	−0.2
2	+1.6	7	−4.5	Noon	+4.9	17	−2.6	22	+1.5
3	−0.2	8	−3.1	13	+4.7	18	−3.4	23	+2.8
4	−2.2	9	−0.9	14	+3.3	19	−3.1	24	+3.2

For the 101 calm days of the year in question the harmonic analysis has been carried out for the 24-hour, 12-hour, and 8-hour waves. ($A_1=217.^\circ6$, $A_2=82.^\circ5$, $A_3=259.^\circ9$; $a_1=0.9$, $a_2=4.1$, $a_3=0.3$, all expressed in millivolts.) This analysis is also carried out for each of the seasons separately; the results were as follows, a being expressed in millivolts:

Coefficient	Winter	Spring	Summer	Autumn
	°	°	°	°
A_1	30.0	225.7	241.9	186.8
A_2	85.7	84.4	82.1	79.6
A_3	180.0	256.0	241.4	284.8
a_1	0.3	1.2	1.3	1.5
a_2	3.6	4.5	5.1	3.2
a_3	0.2	0.2	0.4	0.6

[2] It would appear from this statement that the currents measured and discussed by the Author are to a considerable extent associated with the system of electrodes used rather than true earth currents. It will be recalled that the condition which is usually considered necessary for reliable earth-current measurements is one of *similarity* of electrodes rather than one of *difference*, in order to eliminate spurious effects. In this connection it may be noted that the water-pipe system is described as consisting of "galvanized iron pipe", while the other is referred to only as the "gas-pipe system," and was probably not galvanized.—*S. J. M.*

The harmonic analysis shows for each of the seasons a great preponderance of the 12-hour component. It also shows that the characteristics of the curve do not vary much with the season. The times of maxima and minima, for the 12-hour component, differ from winter to summer by only 6 minutes of time. The curve follows very closely the barometric curve, but with a 2-hour lag.

A rather pronounced relation was observed between direction of wind and departure of the potential-differences from the mean value. When the wind was from the east (from the Continent) or had an easterly component, the potential-differences were always below the mean, while winds from the opposite directions (from the sea) were accompanied by potential-differences greater than the mean.

Another matter of interest is the following: Out of 111 "calm" days of the whole year 1917, there are 45 days whose mean curve is exactly the reverse in form of the mean curve for the remaining days. The former is called "abnormal," and the latter, "normal." The amplitude of the variations on the normal days is about twice as large as on the abnormal days.

MARC DECHEVRENS, S. J.

THE MAGNETIC CHARACTER OF THE YEAR 1916 AND REVIEW OF THE YEARS 1906-1916.

The annual review of the "Caractère magnétique de chaque jour" for 1916 has been drawn up in the same manner as the preceding years; moreover it contains a review of the collaboration of the observatories during the years 1906-1916.

In 1916, 36 observatories contributed to the quarterly reviews; 35 of them sent complete data. Table II of the annual review, containing the mean character of each day and each month, the list of "calm days" and the days recommended for reproduction, is reprinted here. From the review of the years 1906-1916 it appears, that altogether 52 observatories have contributed to the "Caractère magnétique"; an observatory that has been removed is taken with the new one as one station (Potsdam-Seddin, Irkoutsk-Zouy, Tiflis-Karssani, Baldwin-Tucson, Zikawei-Lukiapang).

In a graphical representation the times, for which the observatories sent character-lists, have been indicated by straight lines; if the data have not been made use of in drawing up the annual review, the list having been received too late, or being incomplete, the lines have been drawn thinner.

In the years 1906-1916 successively 35, 37, 43, 42, 43, 45, 43, 43, 43, 37, and 36 stations have contributed; 30, 32, 36, 38, 34, 39, 43, 42, 37, 35, and 35 of them sent complete data, which have been made use of in drawing up the annual reviews; the data of 15 observatories have been employed for all the years 1906-1916, namely: Sitka, Ekaterinburg, Stonyhurst, Wilhelmshaven, Potsdam-Seddin, De Bilt, Greenwich, Kew, Val-Joyeux, Pola, Cheltenham, Honolulu, Bombay, Porto-Rico, and Buitenzorg; from many stations the data for all these years, excepting one or two, were employed.

G. VAN DIJK.

Table Showing the Magnetic Character of the Year 1916.

Dates	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	Mean
January	0.1	0.0	0.4	0.8	0.6	0.5	0.1	0.1	0.7	1.3	1.9	1.6	1.1	0.2	0.1	0.4	0.0	0.3	0.1	1.2	0.6	1.1	1.2	0.7	1.1	0.7	0.2	0.4	0.8	0.1	0.3	0.61
February	0.1	0.1	0.1	0.5	1.0	0.1	0.1	1.2	0.7	0.4	0.2	1.0	0.8	0.7	0.5	0.1	1.0	1.1	0.9	0.8	0.1	0.9	0.7	0.6	0.1	0.8	1.2	0.3	0.1			0.56
March	0.1	0.5	1.2	0.7	0.6	1.0	1.0	1.9	1.9	1.7	0.9	0.8	0.0	0.2	0.1	0.3	1.4	1.0	0.9	1.1	0.9	0.3	0.1	1.3	1.2	0.8	0.0	0.2	1.7	1.5	1.2	0.86
April	0.9	0.3	0.1	0.0	0.1	0.6	0.7	1.1	0.5	0.0	0.3	0.2	0.1	0.7	1.1	1.0	0.5	0.9	0.3	0.8	0.3	0.7	0.3	0.1	1.9	1.4	1.4	1.5	1.8	0.9		0.68
May	0.9	1.0	0.8	0.5	0.9	1.1	0.7	0.7	0.7	0.6	1.0	0.9	0.3	0.2	0.1	0.8	0.7	0.2	0.5	0.3	1.4	1.7	1.3	1.1	0.8	0.3	0.2	0.3	0.7	1.4	1.2	0.75
June	0.8	0.0	0.1	0.1	0.2	0.8	0.9	1.1	0.5	0.1	0.4	0.9	0.9	0.4	0.3	0.0	0.7	1.0	1.1	1.0	0.9	1.3	1.1	0.3	0.9	0.8	0.7	0.8	0.9	1.0		0.67
July	1.6	0.9	0.7	1.0	1.0	0.8	0.3	1.5	1.3	1.0	0.9	0.7	0.7	0.4	0.0	0.3	1.1	0.9	0.6	0.4	0.2	0.3	1.1	0.8	0.2	0.2	0.0	0.1	0.0	0.3	0.1	0.62
August	0.1	1.2	0.6	0.3	1.1	1.5	1.1	1.0	0.7	0.5	0.6	0.4	0.5	0.7	0.0	0.0	0.0	0.1	1.0	1.0	0.8	1.5	1.5	0.9	0.0	1.4	1.9	0.7	1.0	0.7	0.4	0.75
September	0.1	0.8	1.3	1.4	1.2	0.6	0.8	0.6	0.2	1.0	1.2	1.4	0.9	0.3	0.8	1.1	1.1	0.8	0.0	0.0	0.1	0.5	0.7	0.8	0.6	0.9	1.3	0.3	0.1	1.5		0.75
October	1.4	1.2	0.6	0.2	0.8	2.0	1.7	1.4	1.1	0.8	1.2	1.0	1.5	1.0	0.2	0.0	0.1	0.1	0.3	0.8	1.0	1.0	0.9	0.8	0.7	0.2	0.1	0.1	0.9	0.3	0.2	0.76
November	0.4	0.8	1.2	1.4	1.4	1.3	0.9	0.7	0.7	0.5	0.6	1.8	0.9	0.4	0.7	0.5	0.5	0.9	0.7	0.4	0.3	0.6	0.6	0.1	1.1	1.1	1.2	1.0	1.0	1.1		0.83
December	1.4	1.4	1.2	0.9	0.3	0.3	0.3	0.3	0.5	0.3	0.2	1.0	0.8	0.7	1.3	0.9	0.9	0.5	0.2	0.2	0.1	0.0	0.0	0.3	0.7	0.4	1.2	1.1	0.8	1.1	1.0	0.65

Calm Days.

January	2,	8,	15,	17,	19.	February	1,	6,	16,	21,	25.	March	1,	13,	15,	23,	27.
April	4,	5,	10,	13,	24.	May	13,	14,	15,	18,	27.	June	2,	3,	10,	15,	16.
July	7,	15,	27,	28,	29.	August	1,	15,	16,	17,	25.	September	1,	19,	20,	21,	29.
October	4,	16,	17,	18,	28.	November	1,	14,	20,	21,	24.	December	6,	10,	21,	22,	23.

Days Recommended for Reproduction.

** March 8, 9, August 27, October 6.

* January 11, March 10, April 25, April 29, May 21, July 8, August 23, September 30, October 7, November 12.

RECENT PUBLICATIONS

A. Terrestrial and Cosmical Magnetism.

Agincourt and Meanook Observatories. Magnetic observations. May-December, 1917. Toronto, J. R. Astr. Soc. Can., v. 11, 1917 (348-351), (391-395), (426-427); v. 12, 1918 (24), (70), (116-117).

Arctowski, H. Sun spots, magnetic storms, and rainfall. Washington, D. C., U. S. Dept. Agric., Monthly Weath. Rev., v. 45, No. 11, Nov., 1917 (538-539).

Arctowski, H. Orages magnétiques, facules et taches solaires. Paris, C.-R. Acad. sci., T. 165, No. 21, 19 novembre 1917 (713-715).

Chapman, S. Magnetic surveys and charts throughout the world. Abstract: Observatory, London, v. 40, No. 520, Dec., 1917 (445-446). [Paper read at first meeting for the discussion of geophysical subjects, London, Nov. 7, 1917.]

Chapman, S. The diurnal changes of the earth's magnetism. Observatory, London, v. 41, No. 522, Jan., 1918 (52-60).

Chree, C. Magnetic storm and aurora, December 16-17 (1917). Nature, London, v. 100, No. 2514, Jan. 3, 1918 (344).

Chu, Co-Ching. Some Chinese contributions to meteorology. Geog. Rev., New York, N. Y., v. 5, No. 2, Feb., 1918 (136-139). [Contains statements regarding the early use of the magnetic needle among the Chinese.]

Dufour, Ch. Valeur des éléments magnétiques à l'Observatoire du Val-Joyeux au ler janvier 1918. Paris, C.-R. Acad. sci., T. 166, No. 4, 28 janvier 1918 (174-175).

Farr, C. C. A magnetic survey of the Dominion of New Zealand and some of the outlying islands for the epoch 30th June, 1903. (Carried out under the auspices of the New Zealand Government.) Wellington, Lands and Survey Dept. [John Mackay, Govt. Printer], 1916 (64 with 18 maps.). 28 cm.

Flajolet, Ph. Perturbations de la déclinaison magnétique à Lyon (Saint-Genis-Laval) pendant le deuxième trimestre de 1917. Paris, C.-R. Acad. sci., T. 165, No. 25, 17 décembre 1917 (1009).

Flajolet, Ph. Perturbations de la déclinaison magnétique à Lyon (Saint-Genis-Laval) pendant le troisième trimestre de 1917. Paris, C.-R. Acad. sci., T. 166, No. 4, 28 janvier 1918 (175).

Hazard, D. L. Unites States magnetic tables and magnetic charts for 1915. Washington, D. C., U. S. Dept. Comm., Coast Geod. Surv., Spec. Pub. No. 44, 1917 (256 with 5 charts in pocket). 23 cm.

Hazard, D. L. Terrestrial magnetism. Art. in American Year Book, 1917. New York, D. Appleton & Co., 1918 (585-586).

Hongkong, Royal Observatory. Monthly meteorological bulletin, December, 1917. Containing detailed results of observations made at the Royal Observatory, Hongkong, and the daily weather reports from various stations in the Far East. Prepared under the direction of T. F. Claxton, Director. Hongkong, Noronha & Co., Govt. Printers, 1918 (ca. 60 pp. with 2 pls.). 33 cm. [Contains "Results of magnetic observations, 1917."]

Mauritius. Results of magnetical, meteorological and seismological observations for the months of March, April, and May, 1917. New series (monthly), v. 3, Pts. 3, 4 and 5. Royal Alfred Observatory, Mauritius. (A. Walter, Director.) Mauritius, Govt. Press, 1917. 32 cm.

Mauritius. Annual report of the director of the Royal Alfred Observatory for 1916. (A. Walter, Director.) Mauritius, Govt. Press, 1917 (5). 34½ cm.

Palazzo, L. L'eclisse totale di sole del 21 agosto 1914 osservata dalla Missione Italiana in Teodosia (Crimea). Parte geofisica. Relazione 1ª. Registrazioni magnetiche nel tempo dell' eclisse. Estr. Catania, Mem. Soc. spettroscop. ital., v. 6, 1917 (49 pp. con 5 tav.).

Tokyo, Central Meteorological Observatory. Magnetic observations in the year 1913. Tokyo, Japan, Central Meteor. Obs'y, 1917, Ann. Rep. 1913 (46 with 4 pls.). 30 cm.

Toronto Observatory. Results of observations at the Toronto Magnetical Observatory, Agincourt. (Latitude 43° 47′ N. Longitude 79° 16′ W.) The year 1915. Prepared by W. E. W. Jackson under the supervision of Sir Frederick Stupart. Ottawa, Dept. Mar. Can., 1917 (22 with 7 pls.). 29 cm.

United States Coast and Geodetic Survey. Annual report of the Superintendent, United States Coast and Geodetic Survey, to the Secretary of Commerce for the fiscal year ended June 30, 1917. Washington, D. C., Dept. Comm., U. S. Coast Geod. Surv., 1917 (277 with 54 illus.). 23 cm. [Contains general account of magnetic work of the Coast and Geodetic Survey during the fiscal year and sketches showing magnetic stations occupied in the Unites States and possessions to September 30, 1917, together with various reports of field officers in magnetic work.]

United States Naval Observatory. Annual report of the Naval Observatory for the fiscal year 1917. (Appendix No. 2 to the annual report of the Chief of the Bureau of Navigation, 1917.) Washington, D. C., Govt. Print. Off., 1917 (23 with 3 tables). 23 cm. [Contains report of the Department of Compasses, Chronometers, and other Nautical, Aeronautic and Surveying Instruments; the Time Service; the Nautical Instrument Repair Shop; Inspection and Survey, pp. 5-12.]

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Terrestrial Magnetism
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RETURN OF THE *CARNEGIE*, JUNE 1918.

BY L. A. BAUER.

The magnetic survey vessel, *Carnegie*, arrived safely on June 10, at her home port, Washington, D. C., where she will be put out of commission probably during the period of the war. During her cruise from Buenos Aires, Argentina, around The Horn to Valparaiso, Chile, and Callao, Peru, and thence through the Panama Canal to Newport News, she was in command of Dr. H. M. W. Edmonds; the other members of the scientific staff were: Messrs. A. D. Power, Bradley Jones, L. L. Tanguy, J. M. McFadden, and Walter E. Scott.

The scientific work of the *Carnegie* suffered an interruption of nine months in 1917, when it was necessary to detain the vessel at Buenos Aires on account of the methods of sea warfare practised by the German government. For similar reasons, the work of the *Carnegie*, now that she has reached her home port, will have to be suspended for an indefinite period.

The German military authorities have lost a singular opportunity to demonstrate to the world their respect for international science. During a period of warfare, a century and a half ago, the French government issued instructions to its sea commanders that if they fell in with Captain Cook's expedition returning from the South Seas to England, they were to facilitate its passage. No such instructions, as far as it is known, were issued by the German authorities to the German commanders with regard to the *Carnegie*, in spite of the fact of its being well-known in Germany that this vessel has been out on a world cruise since 1915.

The original plans for the *Carnegie* contemplated a return of the vessel to her home port in the spring of 1917; the necessity of detaining her at Buenos Aires, after declaration of war between

Germany and the United States, not only caused a delay of a year in her return but also prevented the completion of very important magnetic work in the South Atlantic Ocean. The German Admiralty, up to the time of the declaration of war, was being supplied promptly, just as were the admiralties of other countries, with the latest magnetic data from the *Carnegie*. In fact; we at one time received a letter from a German official stating that his establishment received from the *Carnegie* magnetic data more promptly than he could obtain similar data from German naval vessels. However, it seemed not to have occurred to any one in Germany to secure assurance to those who were devoting their lives in the pursuit of science for the good of *all* nations, that they would suffer no harm.

The representative of the German government at Buenos Aires was well aware of the cause of the *Carnegie's* detention. If he failed to make representations to the German authorities that protection be assured the *Carnegie* on her homeward cruise, he missed an exceptional opportunity.

RESULTS OF DIP-OF-HORIZON MEASUREMENTS MADE ON THE *GALILEE* AND *CARNEGIE*, 1907-1917.[1]

By W. J. Peters.

The principal work of the Department of Terrestrial Magnetism on the oceans has been that of the magnetic survey. While it has been the desire to include other scientific investigations which might be made advantageously at sea, yet these have been necessarily restricted by the small personnel, and by the extensive program required for the daily magnetic and navigational work. Accordingly, only such additional observations could at first be undertaken that have an important bearing on the magnetic work, or such which would not conflict with the regular schedule. Among these are observations of atmospheric refraction as affecting the dip of the horizon.

Since all astronomic positions at sea depend upon Sun- or star-altitudes measured from the horizon, it is evident that the precision of the determinations of the geographic positions for the magnetic stations at sea will be affected by the error of that value of the refraction which is used in calculating the dip of the horizon. Experience shows that while the refraction for a star may be calculated with sufficient precision for ordinary altitudes, it will be quite uncertain for very low ones, and at the horizon it may even be found with opposite sign to that calculated. Fortunately for astronomic navigation, the path of the optical ray from the horizon passes through a very small portion of the atmosphere compared to rays from the Sun or stars. Thus while the refraction correction to the altitude of a star seen in the horizon may be over ½ degree, the correction to the altitude of the horizon, that is, the dip of the horizon, is ordinarily not more than 1′ or 2′, and its uncertainty is no doubt correspondingly small. While this may be fortunate for astronomic navigation, it is not so for the investigator who tries to ascribe its fluctuations to some physical law, for it is difficult to measure angles of less than 1′ at sea.

Although the atmosphere refraction is *usually* small, reports of extraordinary values from time to time have shown the desirability of extensive investigation, and a number of observations have been made, principally by German investigators, during the last

[1] Presented before the Philosophical Society of Washington, April 27, 1918.

30 years. Koss, who prepared the first tables of dip-of-horizon that have a temperature argument, has observed the horizon 10′ above its normal position and 3′ below. An interesting experience is given in "Tables of Calculated Hour Angles, etc.," by H. S. Blackburne,[2] who says:

"A few years ago an old pupil of the writer, Captain W. H. Sweny, then commanding the P. & O. S. S. *Mooltan*, had a remarkable experience of exceptional refraction on the evening before making Rottnest Light. He took observations of four different stars at about 6 p. m., on April 11, 1910, and afterwards sent to the writer his own observations, asking him to work them out, and let him know what he made the resulting position, but without divulging what he made the result by his own calculations. This was done, and when Captain Sweny afterwards sent the results of his work, both observations were in agreement, and evidently not more than about 1′ in error in either latitude or longitude. The captain also sent the worked-out observations of the other two officers, and from all these observations the writer was able to deduce fairly accurate separate positions, and it was evident from these observations that refraction was excessive all round the horizon, but greatest to the northward, where it was about 11′.0, and in other parts of the horizon averaging about 6¾′, the altitudes being smaller by these amounts than they should have been by allowing the usual tabular corrections."

A German epitome[3] states that the horizon has been observed 15′ above and 3′ below its normal position. Bowditch[4] says that reliable observations have frequently placed it 10′ above, and values as high as 32′ have been recorded. The significance of these figures will be realized when it is remembered that each minute of abnormal refraction means an error of one mile in the position of the ship.

Such extraordinary values of the refraction at the horizon, as cited in the previous paragraph, have not been found during 10 years of work at sea by the Department of Terrestrial Magnetism, covering all the oceans. Whether the large abnormal values may occur along the borders of equatorial and polar currents, shallows, and waters swept by very warm or very cold breezes blowing off land, regions in which the cruises of the *Galilee* and *Carnegie* have not been prolonged, requires further investigation.

In all the observations taken first on the Galilee, then continued on the Carnegie, amounting to 3,031 determinations, the refraction has not raised the horizon more than 2′.4 nor depressed it more than 2′.0 below the position in which it would be seen if no refraction

[2] Blackburne, H. S. Tables of calculated hour-angles and altitude azimuth table 30° N. to 30° S., second edition, p. xxvii.

[3] Lehrbuch der Navigation, herausgegeben vom Reichs-Marine-Amt., second edition, Berlin, 1906, p. 110.

[4] Bowditch, N. American Practical Navigator, Washington, 1914, p. 117.

existed. The observations were made mostly at heights above sea of 24 and 18 feet. The maximum raising of the horizon, $+ 2'.4$, was found on two consecutive days, October 29 and 30, 1915, between New Zealand and Australia; there was a heavy sea at the time and the horizon was noted as "rough." The next maximum raising, $+ 2'.2$, was also observed on two consecutive days, February 9 and 10, 1908, in latitude 41° S., longitude 111° W., when a very high sea, with clear, well-defined horizon, was noted. Values of $+ 2'.0$ occur quite frequently, that is, about 1′ above the average refraction at sea. The maximum depression, $-2'.0$, occurs only once in the 10 years, and was observed August 11, 1914, in latitude 71° N., longitude 5° W., with well-defined horizon and good conditions generally; the position is on the northern edge of the Gulf Stream, and not far from the ice floes of Greenland Sea, in a region where atmospheric conditions are subject to marked changes. Negative values are more rare than positive.

All *methods in use*, up to the present time, for measuring the refraction at the horizon, depend on one common principle—that of measuring the vertical angle between two diametrically opposite points of the horizon, or of measuring the difference between this angle and 180°. This principle, common to all methods, is objectionable because it must be assumed in general that the refraction is the same for opposite points of the horizon. It is possible that unusual values might be observed on occasions when the direction of the abnormal value might be assigned with some degree of plausibility, as, for example, when it is observed from near the edge of an ocean current that may be plainly traced from the vessel, or when mirages occur limited to a small part of the horizon, or by the adjustment of many observations taken about the same time well distributed around the horizon. Experience, however, on the *Galilee* and *Carnegie*, shows that the first two suggestions could only be used on very rare occasions, and the last is not practical on a sailing vessel, where the sails will always interfere with an uninterrupted view of the horizon at a height of 18 feet above water. Heights of less than 18 feet are not desirable in investigations of the refraction.

Among the *instruments available for measuring the dip-of-horizon at sea* are prismatic and reflecting circles, sextants, Troughton's dip sector, the Blish attachment and Kohlschütter's device for sextants, and the dip-of-horizon measurer by Pulfrich. The prismatic circle, sextant, and dip-of-horizon measurer have been tried

on the *Galilee* first, subsequently on the *Carnegie*, but none of these instruments has been found entirely satisfactory. The prismatic circle was acquired primarily for land observations, and was found to be so unwieldy at sea that only a few experiments were attempted. The principal objections to using sextants are the restriction imposed by the limits of their arcs, the much computing usually required to obtain the dip, and the periodic errors of the instrument, which are difficult to control; these errors, of no importance in navigation, are likely to be quite serious in attempts to measure fluctuations in refraction no larger than a fraction of a minute.

The most promising instrument at first seemed to be *Pulfrich's dip-of-horizon measurer*,[5] made by Zeiss, of Jena (Fig. 1). It consists of a low-power telescope, at the object-end of which is attached a box containing a system of 3 reflecting prisms. Rays from opposite points of the horizon enter through perforations or windows, one on each side of the box. They are reflected by the 3 prisms into the telescope. The images of the two opposite portions of the horizon appear as vertical lines. The dark portions of the field represent the sea, and the light band between represents the sky. The dip-of-the-horizon is one-half the angular width of this band, provided, of course, that the instrument is in perfect adjustment. Two methods are used to measure the width of the band; one is a micrometer screw arrangement which moves one of the prisms and enables the observer to bring the two horizons into contact; the other is a fixed-scale arrangement in the focus of the objective. It consists of 2 lines intersecting at a very small angle, on one of which a scale is laid off so that each number of the scale represents the number of minutes or one-half the number of minutes of angular space included between the lines. Fig. 2 shows, for example, that at the point of the scale marked 15 there are 30 minutes of arc between the two diverging lines. A small rotation of the instrument about the horizontal axis of the telescope will bring the images of the two horizons to any part of the scale, so that the trapezoid formed by the horizons and the scale has one of the parallel sides equal to the side formed by the scale. The intersection on the scale of this one of the sides indicates the reading.

The observations with the Pulfrich measurer are made first

[5] Pulfrich, C. Ueber einen Apparat zur Messung der Kimmtiefe, *Zs. Instrumentenk., Berlin*, 1904, Heft 8, pp. 225-229. Moll, E. Der Pulfrich'sche Kimmtiefenmesser, *Hansa*, Hamburg, 1906.

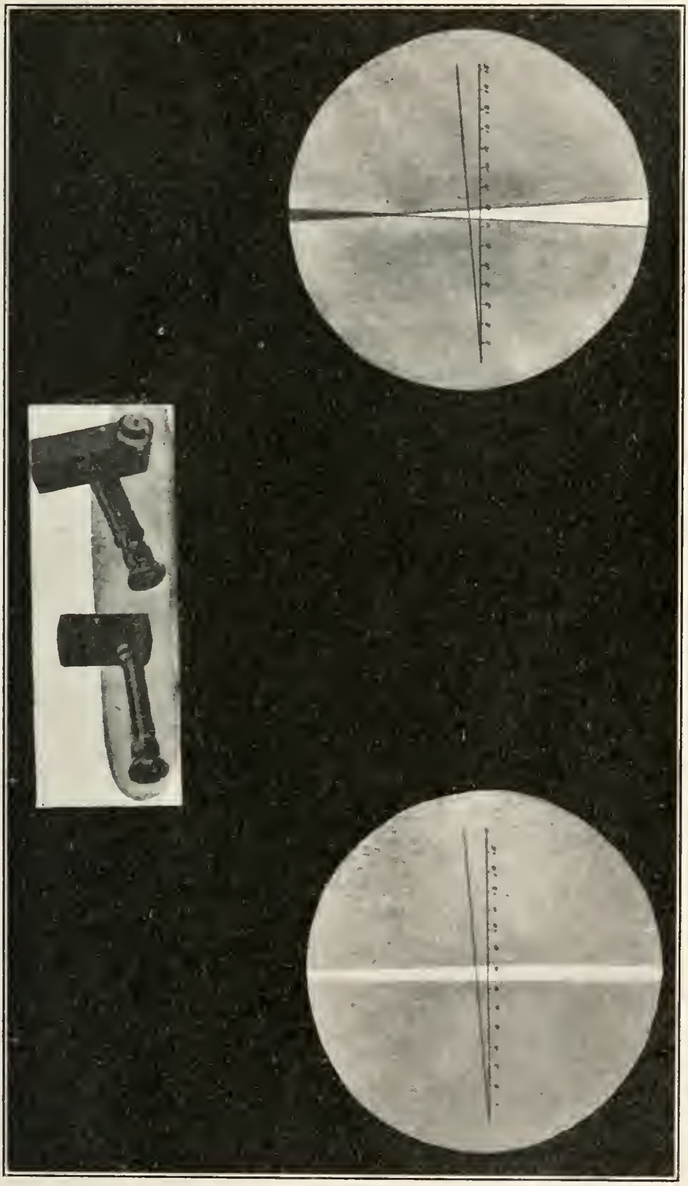

Fig. 1.

Fig. 2.

Fig. 3

with one end of the box up, or erect (E), and then, after rotating the instrument 180° about the horizontal axis of the telescope, the set is completed by a second reading inverted (I). The mean of the two readings is free from errors of maladjustment of the prisms and lack of parallelism in the window glasses. Half of the difference of the two readings, ½ (E-I), is the combined error of maladjustment and lack of parallelism of window glasses, and should remain constant. In the instrument numbered 4048, ½ (E-I) varied from 7′.1 to 7′.8; this change has been attributed to personal error, since careful inspection has not revealed any looseness of the optical parts. The personal error is largest for No. 4048, and might be explained by the fact that the observer has to estimate two trapezoids of quite different aspects. When the instrument is used erect, the trapezoid-area is the sky; when it is inverted, the images of the sea overlap and the trapezoid area becomes a small dark figure. No. 4048 was used on the *Galilee* and the *Carnegie*.

The micrometer form of the Pulfrich measurer seemed to be more satisfactory while using it. The observers state that the observations are more easily made, but the values of the constant, ½ (E-I), show little improvement over those of the fixed-scale form. Error probably occurs when the observer has to decide when the two images of the horizon are in contact and yet not overlapping. A somewhat similar difficulty is found in the determination of index error of a sextant by the sea-horizon method. The result is not so precise as when the sun or stars are used.

The difficulties of observing with the Pulfrich mesaurer *at sea* are increased by the motions of the images as the observer tries to hold the instrument steady. The chief objection is a scissors-like motion which no amount of practice apparently will eliminate; it is caused by changes in the inclination of the telescope to the horizontal. Fig. 3 represents an instantaneous view of the field as the motion is taking place. While the dark and light wedges are continually shifting from top to bottom the observer must decide when the horizons are parallel and must bring the trapezoid to the proper point of the scale at the same instant. He can only do this by a series of approximations. Besides the obstacles to precision which are inherent in this instrument, there are others which affect all instruments.

The actual conditions of visibility, etc., of course are taken care of by the observer's remarks, and these observations may be weighted or rejected, as desired.

One constant source of error is in the height of instrument adopted. Did no refraction exist, the dip-of-the-horizon could be computed for a given height of instrument with more precision than it could be measured. The difference between this computed dip and the dip observed being regarded as the refraction for the given height, it will be in error by the same amount as the computed dip, if the latter is in error. Supposing the given height of about 18 feet to be in error by one foot, the refraction deduced will have an error of 0′.12.

The *height of instrument* is measured in smooth water, as it is not practical to measure it at sea, and it changes with the draft of the vessel, with her rolling and pitching and as she rides the waves and drops into the troughs. Changes in draft are caused by the consumption of water, fuel, and stores, and may be allowed for by assuming a linear change from port to port, where the draft can be accurately read. The *Carnegie's* draft changes about 1½ feet during a long passage. As to the ship's rolling and pitching, it is most probable that observations for dip of horizon are never made on the *Carnegie* when she is inclined as much as 5° to the vertical, since care is taken to make them only on even keel as nearly as can be determined. This precaution was also taken on the *Galilee*.

The error in the height caused by an inclination of 10° is 0.3 foot for a height of 24 feet on even keel, and would cause an error less than 0′.1 in the deduced refraction. An error of this size is not likely to occur, as one can estimate even-keel position closer than 10°, but errors caused by the rolling and pitching of the vessel will always be in the same direction, and can not be entirely eliminated by the mean of many observations. It is more likely to be present on a sailing vessel heeled over by the wind, but even then, if she is on the open sea, she will frequently roll to an upright position. The necessity of precaution is confirmed by notes made on the passage of the *Carnegie* from Port Lyttelton to South Georgia, December, 1915, to January, 1916, in which the observer remarks:

> "When the vessel rolled heavily, as was nearly always the case, the width of light or dark band (that is, double the dip) would increase or diminish 50 per cent of the ordinary value."

As the ship rides the waves and drops into the troughs of the sea, the vertical height of the instrument above mean sea-level changes. The visible horizon is delineated as a straight line by

the crests of the distant waves, if the sea is not too high and irregular. *Accordingly, observations are made only when the vessel rides the waves, on the supposition that the waves are all of the same height and that the instrument will be raised a like amount.* This precaution, however, does not eliminate the whole error, for when the vessel rides the waves, her load water-line is not tangent to the crests of the waves, but always below them. The adopted height therefore, is too high by the vertical height of the waves above the load water-line. The magnitude of the error will depend upon the relative lengths of the ship and the waves, and the angle at which she crosses them. If, for example, long swells reach her broadside on, she will ride them practically at her load water-line.

Observations.—Those on the *Galilee* were made by one observer, using dip-measurer No. 4048. Two readings were always made, sometimes 4, 6, and 8, one-half with instrument erect, the other with inverted position. Those made on the first three cruises of the *Carnegie* were obtained with the same instrument (No. 4048) by different observers. Another instrument, No. 4031, was courteously loaned by the United States Coast and Geodetic Survey during the first two passages of the fourth cruise, after which it was replaced by instrument No. 5490. Every determination of the dip-of-horizon on the fourth cruise of the *Carnegie*, therefore is the result of 2 instruments, and observers were changed every passage or every two passages.

The *data recorded* include the date, latitude, longitude, approximate local time, height of instrument above sea, aspect or definition of the horizon, wind direction and force, air and water temperatures, barometer reading, the directions sighted, cloud notes, and direction of the Sun.

In the adjustments that have been made only those observations were used that were obtained under good conditions of the horizon. In the last few years German investigators of the refraction of the horizon have introduced a temperature coefficient in the adjustment of their observations. The temperature of the air can be measured on the ship, but there is no means of measuring the temperature of the air in contact with the sea at the horizon, so it is assumed that this temperature is the same as the surface of the water at the ship. Both temperatures as ordinarily observed may be subject to errors resulting from the methods used. The water temperature is obtained by immersing a thermometer in a bucket of sea water immediately upon hauling it aboard. This is

a rather crude procedure, but more precise methods are not likely to give better results in the adjustment until larger systematic errors are eliminated.

The temperature of the air as usually measured on board ships has been questioned by Dr. Brehmer[6], who has found errors of 4° C., depending upon the location of the thermometer. Von Karl Willy Wagner[7], after some experiments made on a cable steamer, probably of steel, concluded that errors due to ordinary fixed locations on steamers might amount to 1° and more, and that they usually indicate a temperature higher than the actual air temperature. Exceptional errors of 2° and more were easily explained by heated air rising from a steamer in a calm or traveling with the wind.

The *Carnegie* is built of wood, as was also the *Galilee*. The *Carnegie* is seldom driven by her engine, and the only other sources of heat are the 2 galleys, both of which are well forward of the thermometers. In calm weather this heat, and possibly the heat of the vessel, may raise the temperature slightly, and this may account for some of the large temperature differences found, but it will not account for many. The largest one observed, $-7°.7$ C., is the difference between air of a blizzard blowing at the time, February 11, 1910, and the warm waters of the Gulf Stream. The temperature of the ship could have had little effect, if any, and that would have been to decrease rather than increase this difference.

In attempting to adjust the observations by using a temperature-difference term, the *Galilee* observations were taken up first and a preliminary adjustment was made to determine from them the temperature-difference coefficient which Chauvenet[8] deduces from theoretical considerations and gives in the formula

$$D - D' = 400 \frac{t_a - t_w}{D}$$

in which D is the dip-of-the-horizon (expressed as seconds in the first term and as minutes in the last term), computed on the supposition of no atmospheric refraction, D' the dip affected by refraction, and t_a and t_w the air and water temperatures, respectively,

[6] BREHMER. Nachtrag zur Genauigkeit von Kimmtiefenbestimmungen, *Ann. Hydrogr., Berlin*, v. 39, No. 3, 1911, p. 143.

[7] WAGNER, K. W. Ueber systematische Fehler bei der Messung der Lufttemperatur auf Schiffen, besonders in den Tropen und einige andere Beobachtungen, *Veröff. Met. Inst., Berlin*, No. 244, 1912, pp. 83-95.

[8] CHAUVENET, W. Manual of spherical and practical astronomy, Philadelphia, 1863, v. 1, p. 176.

expressed in Fahrenheit degrees. Chauvenet gives no table for this formula, and evidently has no great confidence in it, for he says:

> "I know of no observations sufficiently precise to determine whether this simple formula deduced from theoretical considerations accurately represents the dip in every case."

The results of the adjustment of the *Galilee* observations show conclusively that the formula will not represent the dip.

The same *Galilee* observations, and also those of the fourth cruise of the *Carnegie* were then adjusted to Koss's equation,[9] which, for a constant height of eye, may be written:

$$D - D' = x + y\ (t_a - t_w)$$

The results are given in Table 1.

The adjustments of the observations of first, second, and third cruises of the *Carnegie* were deferred, pending the results of the adjustment of the fourth cruise, since the observations on this cruise having been made with two instruments with frequent changes of observers might indicate some improvement in methods of observations or adjustment.

The values of x for the *Galilee* are not strictly comparable with those of the *Carnegie*, for a different height of instrument was used. On the *Galilee* it was usually 23.8 feet, while on the *Carnegie* it is 18 feet. However, the difference, about 6 feet, makes very little difference in the value of x, as might be expected.

The range in the values of x might be explained partly by personal or instrumental error, the existence of which *is* suggested by different values that different observers get for the instrumental constant of maladjustment, that is, one-half the difference of reading erect and inverted. The existence of this error appears to be confirmed by the two pairs of values given for the period March 11 to May 21, 1915. The observations during this period and also subsequently were made with two instruments. One was used immediately after the other, so that all conditions, motion, height of instrument, visibility, temperature, etc., were practically identical for each instrument. The difference for the second pair, April 12 to May 21, is unusually large. Its magnitude might be due to the inexperience of the observer, especially as it has not been repeated since, and also as the probable error is about twice as large as the average.

[9] Meyer, H. Kimmbeobachtungen, *Ann. Hydrogr., Berlin*, v. 34, Heft 9, 1906, p. 438.

TABLE 1.—*Results of the adjustment of refraction observations made on board the Galilee, 1907-08, and the Carnegie, 1915-17, according to the equation:* $D-D'=x+y\ (t_a-t_w)$.

(Height of instrument above sea: For the *Galilee*, 23.8 feet, or 725 cm.; for the *Carnegie*, 18 feet, or 549 cm.)

Vessel	Date Interval	x	y	No. of Ob'sns	Probable Error	Average Range in Temp. Diff.	Measurer No.	Observers
	1907	′	′		′	°C.		
Galilee	Mar. 14-Apr. 29	+0.8	+0.1	26	0.09	0.7	4048	W. J. P.
	Apr. 30-June 23	+0.9	+0.1	27	0.17	0.6	"	
	June 24-Aug. 25	+1.0	+0.1	28	0.19	0.4	"	
	Aug. 26-Oct. 15	+0.9	+0.1	26	0.24	0.7	"	
	Oct. 15-Nov. 23	+0.7	+0.1	32	0.18	0.4	"	
	Nov. 24-Dec. 8	+0.8	0.0	24	0.13	0.7	"	
	Dec. 8-Jan. 19	+0.8	+0.1	33	0.21	0.8	"	
	1908							
	Jan. 22-Feb. 13	+1.1	+0.1	28	0.16	0.6	"	
	Feb. 13-Mar. 1	+0.7	−0.1	32	0.13	0.5	"	
	Mar. 1-Apr. 12	+0.6	+0.1	27	0.15	0.5	"	
	Apr. 13-Apr. 25	+0.8	0.0	30	0.11	0.8	"	
	Apr. 26-May 20	+0.6	+0.1	38	0.15	1.2	"	
Galilee	Cruises, 1907-08	+0.81	+0.09	357	....	0.7	4048	
	1915							
Carnegie	Mar. 11-Mar. 24	+0.5	−0.1	31	0.17	1.8	4048	I. A. L.
	Mar. 11-Mar. 24	+0.2	0.0	31	0.21	1.8	4031	I. A. L.
	Apr. 12-May 21	+0.1	+0.1	90	0.31	0.8	4048	H. E. S.
	Apr. 12-May 21	+0.7	0.0	87	0.30	0.9	4031	H. E. S.
	July 3-July 19	+0.7	0.0	34	0.14	1.3	4048 & 5490	I. A. L.
	Aug. 6-Nov. 2	+1.0	0.0	164	0.13	0.9	" "	H. E. S.
	Dec. 6-Jan. 10	+0.9	+0.2	39	0.22	1.1	" "	I. A. L.
	1916							
	Jan. 15-Mar. 31	+1.0	+0.1	111	0.18	1.0	" "	F. C. L.
	May 18-June 6	+1.0	0.0	40	0.11	0.8	" "	F. C. L.
	June 19-July 16	+0.6	0.0	72	0.08	0.8	" "	I. A. L.
	Aug. 8-Sep. 20	+0.7	+0.1	55	0.11	0.7	" "	I. A. L.
	Nov. 2-Dec. 24	+0.8	−0.1	120	0.16	1.1	" "	A. D. P.
	1917							
	Jan. 2-Mar. 1	+0.6	+0.1	107	0.18	1.1	" "	L. L. T.
Carnegie	Cruises 1915-17	+0.79	+0.02	863	....	1.0		

The ranges in x might also be explained by changes in draft of the vessel, and by the height and length of waves. These sources of possible error were not considered until after the adjustments had been made, and so far as known they have not been considered in any previous work. There is a tendency for all low values of x to group themselves in the equatorial regions and high values to occur in the high latitudes, but this distribution, which might be significant, requires further confirmation.

The value of the temperature coefficient, y, changes sign in both series, and the final values which result from including all the observations in one adjustment for each cruise are $+0'.09$ and $+0'.02$, the weighted mean of which is $+0'.04$, if double weight be given to the *Carnegie* value on account of more observations, and that there were two instruments and various observers. This value is practically negligible, for it will not amount to ½ a minute for a temperature difference of 10° C., a larger difference than has been found on our vessels. Koss[10] gives $+0'.33$ for the temperature coefficient, as determined on the Mediterranean and Red seas, where conditions are different from the oceans.

The four largest temperature differences, for the *Galilee* or the *Carnegie*, $t_a - t_w$, are $-7°.7$, $-6°.2$, $-5°.6$, and $+5°.6$, for which the "Nautische Tafeln," based on Koss's temperature coefficient, give the respective dips $7'.7$, $6'.4$, $6'.2$, and $2'.4$, whereas the observed dips were, respectively, $5'.5$, $5'.2$, $5'.8$, and $5'.2$, while the usual tables give the one value $4'.2$ for all temperatures.

From these comparisons it may be concluded that the dip tables based on a temperature difference argument, as published in the "Nautische Tafeln" and the "Nautisches Jahrbuch" are no improvement over those which ignore the temperature, at least for practical use on the deep waters of the ocean.

Table 2, which is an extension of one published in "Annalen der Hydrographie" for 1906,[11] shows the values of x and y as given by various observers. Again these are not strictly comparable, on account of the difference in height of instrument. There is also a big variation in the number of observations. The observations by Koss extend over a year. Meyer's results are from about 287 observations, the *Albert* from 15 equations, each one depending on 1 to 8 observations, the *Carnegie* sextant from 27, and the dip-

[10] Meyer, H. Kimmbeobachtungen, *Ann. Hydrogr., Berlin*, v. 34, Heft 9, 1906, p. 438. See also: Resultate neuerer Kimmtiefenbeobachtungen u. s. w., *Ann. Hydrogr., Berlin*, v. 29, Heft 4, 1901, pp. 164-165.

[11] Meyer, H. Kimmbeobachtungen, *Ann. Hydrogr., Berlin*, v. 34, Heft. 9, 1906, p. 448.

TABLE 2.—*Various determinations of the constant part of refraction, x, and the temperature coefficient, y, in the equation:* $D-D'=x+y\ (t_a-t_w)$.

Height of Instrument	x	y	Observer
ft.	′	′	
21.2	+0.25	+0.35	Koss.
33.3	+0.30	+0.36	Koss.
20.0	+0.33	+0.34	Meyer.
20.5	+0.44	+0.30	Meyer.
29.5	+0.47	+0.29	Meyer.
22.6	+0.44	+0.47	U. S. S. *Albert.*
23.8	+0.81	+0.09	*Galilee.*
18.0	+0.79	+0.02	*Carnegie.*
18.0	−0.20	−0.06	*Carnegie* (sextant).

measurer results from both *Galilee* and *Carnegie* are deduced from over 1,000 observations. Koss's results are from theodolite observations on a point of land. Meyer's come mostly from prismatic-circle observations. The instrument used on the U. S. S. *Albert* is not known.

The sextant observations on the *Carnegie* were made by an observer of unusual skill with this instrument. Index errors were determined for each day's set, and periodic errors were controlled by shore observations at the close of the series. The result differs very much from all others. The explanation might be that the periodic errors were not stable, or that the magnifying power was too low.

Comparisons with the dip-of-horizon tables ordinarily used, that is to say, with tables in which the temperature difference is disregarded, is most conveniently made by referring to the equations on which these tables are constructed, as shown in Table 3.

Conclusions.

1. The dip-of-horizon tables in common use which ignore air-water temperature differences are sufficiently accurate for the navigator.

2. Extraordinary values such as quoted in the beginning of this paper may possibly occur occasionally in certain regions, where one should be ready to detect them either by observing stars in different azimuths or by special instruments or attach-

TABLE 3.

Table	Equation for dip-of-horizon	Dip	
		16 ft.	50 ft.
	′	′	′
Chauvenet,[12] Bowditch[13], Inman[14]	$0.980\sqrt{h}$ ft.	3.9	6.9
Martin[15]	$0.984\sqrt{h}$ ft.	3.9	7.0
Nautisches Jahrbuch[16]	$1.005\sqrt{h}$ ft.	4.0	7.1
Nautische Tafeln[17]	$0.978\sqrt{h}$ ft.	3.9	6.9
Galilee, II, III; *Carnegie*, IV	$0.89\ \sqrt{h}$ ft.	3.6	6.3

ments to the sextant. Even if the direction of the abnormal value is uncertain, the knowledge of its existence is a factor of safety.

3. During the 10 years of observations of atmospheric refraction made aboard the *Galilee* and the *Carnegie*, in all the oceans, amounting to 3,031 determinations, the observed values of refraction have not raised the horizon more than $2'.4$, nor depressed it more than $2'.0$ below the position it would be seen, if no refraction existed.

4. If aerial navigation across the oceans is eventually realized, which seems quite likely, and astronomic methods are used, then simple means of measuring the dip-of-the-horizon might be very desirable, if not absolutely essential. At present the aviator determines the height of his ship by the aneroid, which has not the precision necessary for computing the dip.

[12] CHAUVENET, W. Manual of spherical and practical astronomy, Philadelphia, 1863, v. I, p. 177.

[13] BOWDITCH, N. American Practical Navigator, Washington, 1914, p. 509.

[14] INMAN, J. Nautical tables designed for the use of British seamen, London, 1906, p. ix.

[15] MARTIN, W. R. A treatise on navigation and nautical astronomy, third edition, London, 1899, p. 147.

[16] Lehrbuch der Navigation, herausgegeben vom REICHS-MARINE-AMT., second edition, Berlin, 1906, p. 111.

[17] Nautische Tafeln der K. und K. Kriegs-Marine, Pola, 1902, p. xvi.

DEPARTMENT OF TERRESTRIAL MAGNETISM,
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RELATION BETWEEN THE SECULAR VARIATION OF THE EARTH'S MAGNETISM AND SOLAR ACTIVITY.—*Continued.*[13]

By L. A. Bauer.

27. Table 8 contains the quantities Σg^2 and r for the 8 observatories enumerated in the first column, for which the G-formulæ are given in Table 5. After the column designating the observational series used, the quantities are given first for the formulæ without the sun-spot- or s-term, and next for the formulæ with the s-term. The particular formula used is shown in the "For."-columns. The last column indicates the lag assumed in the formulæ with the s-term. The following formulæ, referred to in Table 8 do not appear in Table 5:

	$\gamma \quad \gamma \qquad\qquad\qquad \gamma$
Potsdam, 1891-1916, II*d*:	$G=28632.4-1\ .90\ (T\text{-}1904.0)-1.091\ (T\text{-}1904.0)^2$
Sitka, 1904-1916, VI*c*:	$G=32182.4-26.49\ (T\text{-}1910.5)-0.107\ (T\text{-}1910.5)^2$

As will be recalled, g is the residual obtained by subtracting the computed value of G from the observed value. It will be seen that for each observatory the sum of the residuals squared, as also the probable error of a result, has been diminished by the introduction in the formula of a term depending upon a distinct physical cause—solar activity.

Table 9 contains the same quantities with respect to F, the total intensity, as did Table 8 with respect to G. The F-formulæ used are those in Table 6. The sum of the residuals squared, or Σf^2, has been diminished for each observatory when the solar-activity term was introduced in the F-formula. In two instances, Sitka and Cheltenham, the probable error, r, was somewhat increased with the introduction of the s-term in the provisional formulæ.

In general it appears that the secular-variation expressions have been improved by including a term depending upon sun-spot activity. The improvement is not so marked for the shorter series as for the longer series of observations, owing, doubtless, to the difficulty of determining from a series not extending over more than one sun-spot cycle the regular course of the secular variation. Thus there may be included in the values of the coefficients y

[13] See *Terr. Mag.*, vol. 23, pp. 1-22.

and z, equations (9) and (10), some of the short-period effects of solar activity. It is of interest to note in this connection that the two exceptions in which r for F was not improved, apply to stations (Sitka and Cheltenham) which have the largest values of y and z F (see Table 6).

Table 8.—*Values of Σg^2 and of r for the G-formulæ.*

Station	Series	Without s-term			With s-term			
		For.	Σg^2	r	For.	Σg^2	r	Lag
				γ			γ	Yrs.
Kew	1891–1915	I	4028	±9.1	I*c*	2088	±6.7	3
Potsdam	1891–1916	II*d*	2348	±6.8	II*b*	1447	±5.5	2
Pola	1904–1915	III	669	±5.8	III*b*	548	±5.6	4
Alibag	1904–1915	IV*a*	1060	±7.3	IV*b*	817	±6.8	0
Honolulu	1904–1915	V*c*	167	±2.9	V*d*	80	±2.1	0
Sitka	1904–1916	VI*c*	337	±3.9	VI*b*	158	±2.8	3
Cheltenham	1904–1916	VII*a*	1347	±7.8	VII*b*	1149	±7.6	0
Porto Rico	1904–1916	VIII*a*	782	±6.0	VIII*b*	543	±5.3	4

Table 9.—*Values of Σf^2 and of r for the F-formulæ.*

Station	Series	Without s-term			With s-term			
		For.	Σf^2	r	For.	Σf^2	r	Lag
				γ			γ	Yrs.
Kew	1891–1915	I′	7459	±12.4	I′*a*	5287	± 9.2	0
Potsdam	1891–1916	II′*a*	11569	±15.1	II′*c*	11057	±15.1	2
Pola	1904–1915	III′	2356	±10.9	III′*a*	2106	±10.9	4
Alibag	1904–1915	IV′*a*	1549	± 8.9	IV′*b*	1232	± 8.4	0
Honolulu	1904–1915	V′	277	± 3.7	V′*a*	231	± 3.6	0
Sitka	1904–1916	VI′	1178	± 7.3	VI′*b*	1171	± 7.7	3
Cheltenham	1904–1916	VII′	11294	±22.6	VII′*a*	10739	±23.3	0
Porto Rico	1904–1916	VIII′	2753	±11.2	VIII′*a*	2325	±10.8	0

28. Let us obtain now an approximate numerical estimate of the magnetic effects associated with changes in sun-spottedness. Table 10 gives the values of the coefficient s of the sun-spot term, as taken from Tables 5 and 6; this coefficient is the magnetic effect on G (or F) corresponding to an increase of 1 in the sun-spot number. The particular value of s taken from Table 5 or 6 will be identified by the columns of lag in Table 10. The mean value of s for the 8 observatories is -0.285γ for G, and -0.244γ for F. *Hence, on the average, an increase of 10 in the sun-spot number*

was accompanied apparently, during 1891-1916, by a decrease of about 2.85γ in G, or about 0.01 per cent of G, and a decrease of 2.44γ in F, or about 0.005 per cent of F.

The maximum annual changes in the sun-spot numbers, for the period 1904-1916, occurred between 1909 and 1910 (−25.3), and between 1914 and 1915 (+36.4), or 31 on the average, corresponding to an effect on *G* of 8.8γ and on *F* of 7.6γ—appreciable quantities. The range in the effects on *G* and *F* between the sun-spot maximum of 1905 and the sun-spot minimum of 1913 was 17.7γ and 15.2γ, respectively.

TABLE 10.—*Values of coefficient, s, of sun-spot term.*

Station	Series	G		F	
		Lag	*s*	Lag	*s*
		Yrs.	γ	Yrs.	γ
Kew	1891–1915	3	−0.353	3	−0.364
Potsdam	1891–1916	2	−0.343	2	−0.170
Pola	1904–1915	4	−0.269	4	−0.417
Alibag	1904–1915	0	−0.268	0	−0.316
Honolulu	1904–1915	0	−0.127	4	−0.095
Sitka	1904–1916	3	−0.374	3	+0.204
Cheltenham	1904–1916	0	−0.219	0	−0.279
Porto Rico	1904–1916	4	−0.426	4	−0.511
	Means	2	−0.285	2.5	−0.244

THE SECULAR VARIATION, SUN-SPOT CYCLE, AND SOLAR RADIATION.

29. Let us next examine especially the *magnetic results obtained during the period 1905-1915*, for which we have, in addition to the evidences of solar activity from sun-spottedness, those revealed by changes in solar radiation as shown by the solar-constant values observed by the Smithsonian Institution at Mt. Wilson, California. Some use has already been made of the solar-constant data in the paper cited in paragraph 1. Dr. Abbot has very courteously supplied the Department of Terrestrial Magnetism with his later data in advance of publication; grateful acknowledgment is here made to him, as well as to the Superintendent of the Coast and Geodetic Survey for the most recent values of the magnetic elements at the magnetic observatories of his bureau.

Table 11 contains the mean magnetic residuals for 1905-1915, as derived from the 8 magnetic observatories for which the formulæ

are given in Tables 5 and 6. The residuals g and f were obtained by subtracting from the observed values of G and F the computed ones, derived from the formulæ *without* sun-spot term. The residuals g' and f' were obtained by subtracting from the observed values of G and F the computed ones, derived from the formulæ *with* sun-spot term. Comparisons of the values of g with those for g', and of f with those for f', show once more the improvement effected by taking into account a term depending upon solar activity. Thus we have:

Σg^2	$\Sigma(g')^2$	Σf^2	$\Sigma(f')^2$
136.4	81.3	167.2	107.8

30. The curves for g and f will be found plotted in Fig. 5, below the sun-spot curve (S.S.). As lag was taken into consideration for the (g)-curve, it shows the most similarity with the sun-spot curve.[14] Some rather striking features are found, however,

TABLE 11.—*Mean magnetic residuals.*

Date	Without s-term		With s-term	
	g	f	g'	f'
	γ	γ	γ	γ
1905.5	+1.6	+0.9	+0.4	−0.9
06.5	+4.9	+1.9	+2.8	−0.9
07.5	+2.3	+3.4	+3.6	+2.8
08.5	+0.5	+2.4	+3.4	+1.8
09.5	−5.4	−4.1	−2.0	−2.0
10.5	−4.4	−5.1	−3.1	−4.5
11.5	−4.2	−7.4	−2.9	−5.1
12.5	+0.9	+1.4	0.0	+1.6
13.5	+4.3	−6.1	+1.6	−5.2
14.5	+1.1	−2.9	−2.2	−3.9
15.5	−4.2	+0.5	−4.4	+0.2

in the magnetic curves for which we do not find precise counterparts in the sun-spot curve. The next curve (S.C.) is a graph of the solar-constant values; the values for the mean of the year have been obtained by scalings from a graph of the mean seasonal values (June to October), as derived from Abbot's observed values; they differ but slightly from Abbot's mean results for the period

[14] With the aid of data received recently, it is possible to give now the final sun-spot number for 1916, viz., 55.4, instead of the provisional value (70), which appeared in Table 7, and was mentioned in the first line, p. 22.

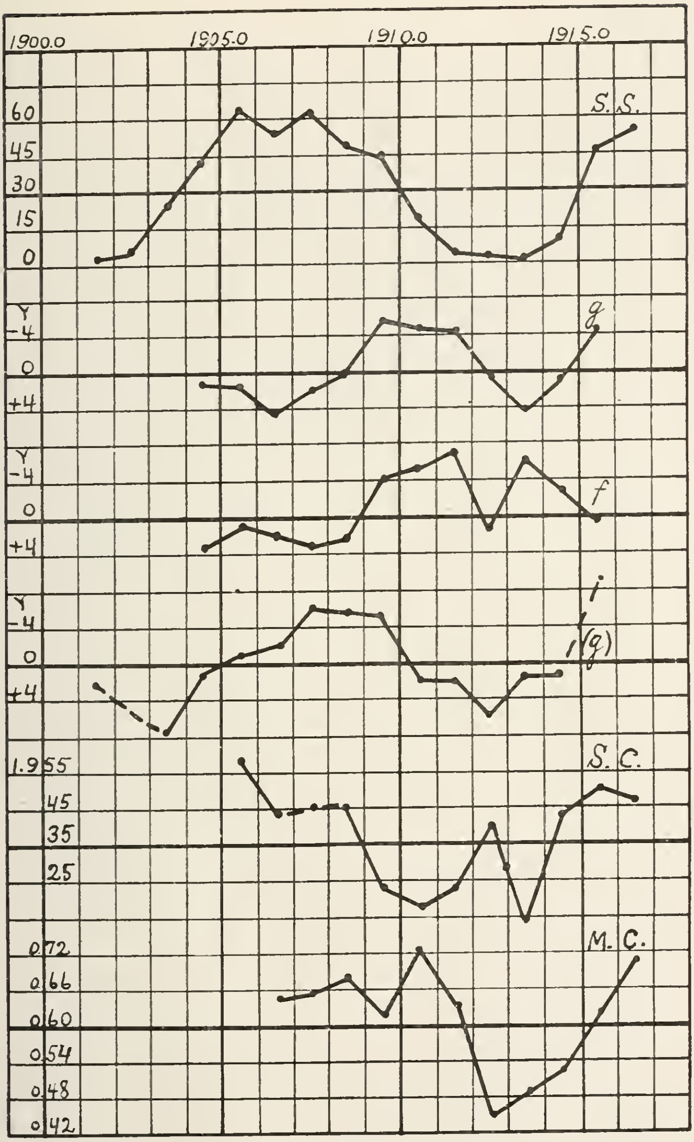

FIG. 5.—Curves Showing the *g*- and *f*- Effects, 1905-1915.

of observation at Mt. Wilson, which generally covers about 5 months of each year. The portion of the curve between 1906 and 1908 is broken, as there were no solar-constant observations in 1907. Comparing the S.C.-curve with the magnetic curves, it would appear that we may have a clue as to the cause of some of the outstanding features. The magnetic effects are, of course, *combined* effects from various sources of solar activity. It may well be, therefore, that some magnetic effects will be found associated with such manifestations of solar activity, of the noneruptive type, as are revealed to us by changes in the solar constant of radiation rather than by sun-spottedness.

31. The pronounced lag in the magnetic curves, g and f, with respect to the sun-spot maximum of 1905 and 1907 already mentioned in paragraph 26 for Kew, Potsdam, and Bombay, is also shown by another set of numbers—the so-called international annual magnetic-character numbers. The latter numbers will be found plotted in the bottom curve (M.C.). It will be seen that the crest of the M. C.-curve occurs as late as 1910.5, or about midway between the crests of the g- and f-curves. There is comparatively but little lag, however, in all the magnetic curves, with respect to the period of minimum solar activity, as shown both by the sun-spot numbers and the solar-constant values. Thus we are led once more to the suggestion made in paragraph 26, that *the lag in the magnetic effects is a variable quantity and appears to depend upon the degree of solar activity.*

32. The residuals, g' and f', which have been tabulated in Table 11, are plotted in Fig. 6. These residuals are the preliminary outstanding effects, after the long-period or regular portion of the secular variation and the portion which may be associated with sun-spottedness have been eliminated from the values of G and F, as well as this can be done on the basis of series of observations from 1905-1915 at 8 magnetic observatories encircling the globe. The elimination of the regular or cyclic effects is of course not to be regarded as a perfect one, but merely as a preliminary attempt; to make a more perfect elimination it is necessary to have longer series of observations.

The bottom curve (S. C.) of Fig. 6 is again that of the solar-constant values. A comparison of the 3 curves confirms the impression once more that we may have magnetic effects associated with such changes in solar activity as are indicated to us by changes in the solar constant of radiation.

33. The second column of Table 12 contains the mean annual values of the quantity $G=\sqrt{H^2+\frac{1}{4}Z^2}$ for the 8 observatories, Kew, Potsdam, Pola, Alibag, Honolulu, Sitka, Cheltenham, and Porto Rico. The third, fourth, and fifth columns contain the residuals found by subtracting from the observed values of G those computed by the following secular-variation formulæ expressed in gammas ($1\gamma=0.00001$ C. G. S.):

$$G=31982.0-27.15\,(T-1910.5) \qquad (12)$$
$$G=31982.0-28.64\,(T-1910.5)-0.286\,(N-32.4) \qquad (12a)$$
$$G=31982.0-28.36\,(T-1910.5)-0.192\,[(N-32.4)+10^3\,(C-1.937)] \qquad (12b)$$

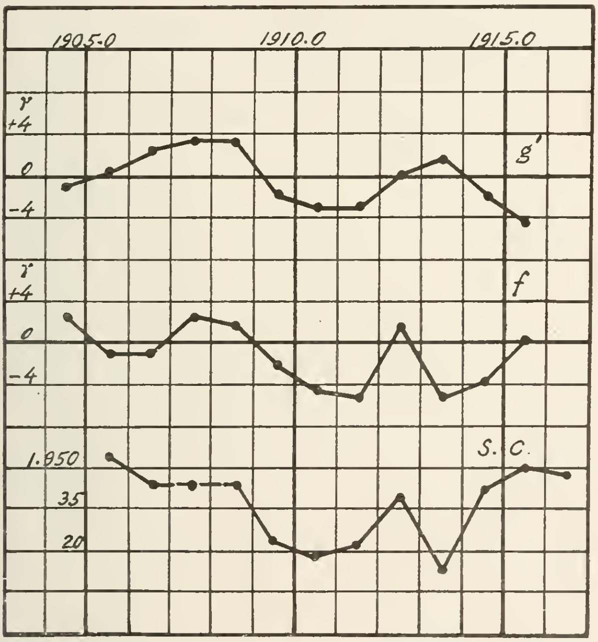

FIG. 6.—Curves Showing the g'- and f'- Effects, 1905-1915.

N is the Wolfer sun-spot number; C is the solar constant, expressed in gram-calories per square centimeter per minute and referred to a point outside the atmosphere and at the Earth's mean solar distance.

The improvement effected by the successive formulae is shown by the sums of the residuals squared, Σg^2, and the probable errors, r, tabulated at the bottom of the table. It will also be seen that the distribution of the residuals has been successively improved.

Thus we see once more how the introduction of a term depending upon solar activity results in a marked improvement in the secular-variation formula, and how thereby the number of arbitrary coefficients for which no physical cause can at present be assigned is reduced.

TABLE 12.—*Results of secular-variation formulæ for mean values of G.*

Date	Mean	Residuals		
	G	(12)	(12a)	(12b)
	γ	γ	γ	γ
1905.5	32106	−12	−10	−8
06.5	2089	− 1	− 1	−1
07.5	2066	+ 2	+ 7	+6
08.5	2041	+ 5	+ 6	+7
09.5	2011	+ 2	+ 4	0
10.5	1986	+ 4	0	−2
11.5	1958	+ 4	− 3	−3
12.5	1934	+ 7	+ 1	+4
13.5	1907	+ 6	+ 2	0
14.5	1871	− 2	− 3	0
15.5	1832	−14	− 3	−3
	Σg^2	487	234	199
	r	± 5.0	± 3.6	±3.4

The best expression (12b) it will be noticed contains a solar-activity term as dependent both upon sun-spottedness and the solar-constant values. The establishment of a preliminary expression in which the sun-spot term and the solar-constant term appeared independently showed that the decrease in G for an increase of 10 in the sun-spot number, N, was 1.87γ, and for an increase of 0.010 in the solar constant, C, the decrease in G was 1.97γ. Hence the magnetic effect of a change of 10 in N was assumed provisionally equal to a change of 0.010 (about one-half per cent) in C. A new least-square adjustment, represented by formula (12b) was then made.

34. When the present sun-spot maximum has been well passed and thus a few more years of observations of both magnetic and solar quantities are available, it will be possible to determine better, than can be done now, the magnetic effects to be associated respectively with sun-spot activity and solar-constant changes.

It would seem that we have ample evidence that the Earth's absolute magnetic state at any time is dependent upon solar conditions, and that an appreciable portion of the secular variation of the Earth's magnetism may be associated with changes in solar activity. In general, the effect of increased solar activity is to cause a decrease in the Earth's intensity of magnetization, though there may also at times be reverse effects.

PRELIMINARY RESULTS OF OCEAN MAGNETIC OBSERVATIONS ON THE CARNEGIE FROM TALCAHUANO TO BALBOA, JANUARY TO APRIL, 1918.[1]

By H. M. W. Edmonds, Commanding the *Carnegie*.

(Observers: H. M. W. Edmonds, A. D. Power, B. Jones, L. L. Tanguy, J. M. McFadden, and W. E. Scott.)

Date	Latitude	Long. East of Gr.	Carnegie Values			Chart Differences[2]					
						Decl'n and Incl'n			Hor. Int.[3]		
			Decl'n	Incl'n	Hor. Int.	Brit.	Ger.	U.S.	Brit.	Ger.	U.S.
1918	° ′	° ′	°	°	c. g. s.	°	°	°			
Jan. 23	36 23 S	286 49	....	34.5 S	.265	0.3 S	1.8 N	.....	−4	− 6	−12
23	36 09 S	286 41	15.1 E	....	.....	0.2 E	0.9 E	0.2 W	.....	.....	.....
24	35 33 S	286 13	14.9 E	....	.....	0.0	0.6 E	0.4 W	.....	.....	.....
24	35 30 S	286 11	15.0 E	....	.....	0.1 E	0.7 E	0.3 W	.....	.....	.....
24	35 11 S	285 57	....	33.6 S	.268	0.2 S	1.8 N	.....	−1	− 4	−10
24	34 56 S	285 47	15.1 E	....	.....	0.2 E	0.8 E	0.0	.....	.....	.....
25	33 45 S	285 10	14.6 E	....	.....	0.1 W	0.3 E	0.4 W	.....	.....	.....
25	32 49 S	284 46	....	31.6 S	.267	0.5 S	1.4 N	.....	0	− 5	−12
25	32 34 S	284 38	14.9 E	....	.....	0.4 E	0.8 E	0.2 E	.....	.....	.....
26	31 30 S	284 08	14.6 E	....	.....	0.3 E	0.5 E	0.0	.....	.....	.....
26	31 15 S	284 05	....	30.0 S	.268	0.2 S	2.0 N	.....	0	− 5	−12
26	31 04 S	283 56	14.7 E	....	.....	0.4 E	0.6 E	0.1 E	.....	.....	.....
27	30 48 S	283 40	14.6 E	....	.....	0.3 E	0.4 E	0.0	.....	.....	.....
27	30 47 S	283 31	....	29.6 S	.270	0.6 S	1.7 N	.....	+2	− 4	−10
27	30 30 S	283 15	14.9 E	....	.....	0.6 E	0.7 E	0.1 E	.....	.....	.....
28	29 28 S	282 09	14.7 E	....	.....	0.4 E	0.4 E	0.2 W	.....	.....	.....
28	28 54 S	281 21	....	28.4 S	.275	1.1 S	2.0 N	.....	+4	− 3	− 8
28	28 40 S	280 59	14.6 E	....	.....	0.2 E	0.2 E	0.3 W	.....	.....	.....
28	28 34 S	280 50	14.8 E	....	.....	0.4 E	0.4 E	0.1 W	.....	.....	.....
29	27 36 S	279 14	14.4 E	....	.....	0.0	0.2 W	0.5 W	.....	.....	.....
29	27 24 S	278 33	....	28.4 S	.276	2.4 S	1.6 N	.....	0	− 7	−10
29	27 17 S	278 08	15.0 E	....	.....	0.3 E	0.2 E	0.0	.....	.....	.....
29	27 16 S	278 04	14.9 E	....	.....	0.2 E	0.1 E	0.1 W	.....	.....	.....
30	27 52 S	276 08	15.3 E	....	.....	0.0	0.3 W	0.4 W	.....	.....	.....
30	28 18 S	275 21	....	30.8 S	.280	2.9 S	1.6 N	.....	+2	− 5	− 7
30	28 34 S	274 59	15.4 E	....	.....	0.4 W	0.7 W	0.7 W	.....	.....	.....
31	29 24 S	273 31	16.4 E	....	.....	0.1 E	0.2 W	0.2 W	.....	.....	.....
31	29 47 S	272 51	....	33.8 S	.279	3.7 S	1.9 N	.....	−1	− 8	− 9
31	30 06 S	272 32	16.6 E	....	.....	0.0	0.5 W	0.4 W	.....	.....	.....
Feb. 1	31 05 S	271 44	16.9 E	....	.....	0.2 W	0.8 W	0.7 W	.....	.....	.....
1	31 41 S	271 06	....	36.7 S	.280	4.1 S	2.0 N	.....	−2	− 6	− 7
1	31 59 S	270 45	17.2 E	....	.....	0.3 W	1.0 W	0.9 W	.....	.....	.....
2	32 44 S	269 30	17.8 E	....	.....	0.0	0.8 W	0.5 W	.....	.....	.....
2	33 23 S	269 06	....	39.5 S	.280	4.8 S	1.8 N	.....	−3	− 5	− 6
2	33 55 S	268 49	18.5 E	....	.....	0.2 E	0.6 W	0.3 W	.....	.....	.....
3	35 07 S	268 10	18.8 E	....	.....	0.0	0.9 W	0.5 W	.....	.....	.....
3	35 42 S	268 12	....	42.2 S	.277	4.8 S	2.2 N	.....	−7	− 6	− 7
4	36 52 S	268 25	19.4 E	....	.....	0.2 W	0.9 W	0.8 W	.....	.....	.....
4	36 56 S	268 51	....	43.4 S	.276	5.0 S	2.0 N	.....	−7	− 6	− 7
4	36 58 S	268 58	19.8 E	....	.....	0.2 E	0.4 W	0.4 W	.....	.....	.....
5	36 57 S	269 54	20.0 E	....	.....	0.5 E	0.1 W	0.2 W	.....	.....	.....

[1] For previous table, see *Terr. Mag.*, v. 23, pp. 23-24.

[2] Charts used for comparison: U. S. Hydographic Office Chart No. 2406 for 1915 and No. 1701 for 1900; British Admiralty Charts No. 3777 for 1917, Nos. 3598 and 3603 for 1907; Reichs-Marine-Amt Charts Tit. XIV, No. 2 for 1910, Tit. XIV, Nos. 2a and 2b for 1905. The chart differences are obtained by subtracting corrected chart values, derived as explained in previous sentence, from the observed *Carnegie* values. The letter *E* signifies that the chart value for east declination is smaller, or the chart value for west declination larger, than the *Carnegie* value; *W* signifies the reverse. The letter *N* signifies that the derived chart value for northerly inclination is smaller, or for southerly inclination larger, than the *Carnegie* value; *S* signifies the reverse. The plus sign signifies that the derived chart value for horizontal intensity is smaller than the *Carnegie* value, the minus sign meaning, of course, the reverse.

[3] Expressed in units of third decimal c. g. s.

Date	Latitude	Long. East of Gr.	Carnegie Values			Chart Differences[2]					
						Decl'n and Incl'n			Hor. Int.[3]		
			Decl'n	Incl'n	Hor. Int.	Brit.	Ger.	U.S.	Brit.	Ger.	U.S.
1918	° ′	° ′	°	°	c.g.s.	°	°	°			
Feb 5	36 55 S	270 20	....	42.5 S	.277	4.3 S	2.1 N	.....	− 5	− 6	− 7
5	36 54 S	270 30	19.7 E	....	.....	0.3 E	0.2W	0.5W	.....	.....	.....
6	36 57 S	271 31	20.0 E	....	.....	0.7 E	0.2 E	0.1W	.....	.....	.....
6	36 58 S	272 25	....	41.5 S	.276	3.7 S	2.3 N	.....	−4	− 8	− 9
6	36 58 S	272 47	19.3 E	....	.....	0.1 E	0.0	0.6W	.....	.....	.....
7	36 58 S	274 11	19.2 E	....	.....	0.2 E	0.2 E	0.4W	.....	.....	.....
7	36 57 S	275 28	....	40.2 S	.274	3.0 S	2.0 N	.....	−4	−10	−11
7	36 56 S	275 55	18.9 E	....	.....	0.2 E	0.3 E	0.2W	.....	.....	.....
7	36 56 S	276 02	19.0 E	....	.....	0.3 E	0.5 E	0.1W	.....	.....	.....
8	36 29 S	277 42	18.3 E	....	.....	0.2 E	0.6 E	0.3W	.....	.....	.....
8	35 54 S	278 43	....	37.6 S	.272	2.1 S	2.0 N	.....	−3	− 8	−12
8	35 38 S	279 02	17.5 E	....	.....	0.1 E	0.5 E	0.7W	.....	.....	.....
9	34 41 S	278 56	17.5 E	....	.....	0.4 E	0.8 E	0.5W	.....	.....	.....
9	33 59 S	278 42	....	35.6 S	.272	2.2 S	1.6 N	.....	−2	− 8	−13
10	32 27 S	278 34	16.4 E	....	.....	0.1W	0.3 E	0.7W	.....	.....	.....
10	31 49 S	278 36	....	33.0 S	.274	2.0 S	2.1 N	.....	+1	− 7	−11
10	31 36 S	278 36	16.4 E	....	.....	0.2 E	0.5 E	0.3W	.....	.....	.....
11	30 41 S	278 27	16.1 E	....	.....	0.2 E	0.3 E	0.2W	.....	.....	.....
11	30 06 S	278 21	....	31.3 S	.275	2.2 S	1.9 N	.....	+1	− 6	−10
11	30 00 S	278 18	15.9 E	....	.....	0.3 E	0.2 E	0.2W	.....	.....	.....
11	29 55 S	278 19	16.0 E	....	.....	0.4 E	0.3 E	0.1W	.....	.....	.....
11	29 51 S	278 22	16.0 E	....	.....	0.4 E	0.4 E	0.0	.....	.....	.....
12	28 18 S	278 11	15.1 E	....	.....	0.1 E	0.0	0.3W	.....	.....	.....
12	27 51 S	278 09	....	28.8 S	.276	2.4 S	1.9 N	.....	+1	− 7	−10
12	27 32 S	278 08	15.0 E	....	.....	0.3 E	0.0	0.1W	.....	.....	.....
13	26 09 S	278 06	14.3 E	....	.....	0.2 E	0.3W	0.3W	.....	.....	.....
13	25 27 S	278 14	....	25.7 S	.279	2.1 S	2.1 N	.....	+2	− 6	− 8
13	25 15 S	278 15	14.0 E	....	.....	0.3 E	0.2W	0.2W	.....	.....	.....
14	24 06 S	278 29	13.8 E	....	.....	0.6 E	0.1W	0.0	.....	.....	.....
14	23 53 S	278 32	....	23.1 S	.281	1.8 S	2.4 N	.....	+2	− 5	− 7
14	23 46 S	278 35	13.7 E	....	.....	0.7 E	0.0	0.1 E	.....	.....	.....
15	22 41 S	278 57	12.8 E	....	.....	0.3 E	0.5W	0.4W	.....	.....	.....
15	22 20 S	279 01	....	20.7 S	.284	1.6 S	2.5 N	.....	+4	− 4	− 5
15	22 08 S	279 09	13.0 E	....	.....	0.8 E	0.0	0.0	.....	.....	.....
16	21 02 S	279 44	12.0 E	....	.....	0.3 E	0.5W	0.5W	.....	.....	.....
16	20 47 S	279 50	....	17.7 S	.286	1.3 S	3.3 N	.....	+4	− 3	− 5
17	19 51 S	280 28	12.0 E	....	.....	0.8 E	0.1 E	0.1 E	.....	.....	.....
17	19 36 S	280 40	....	15.2 S	.287	0.3 S	3.3 N	.....	+4	− 4	− 5
17	19 25 S	280 50	11.3 E	....	.....	0.3 E	0.4W	0.4W	.....	.....	.....
18	18 35 S	281 32	11.0 E	....	.....	0.4 E	0.3W	0.4W	.....	.....	.....
18	18 07 S	281 40	....	12.1 S	.291	0.1 N	3.7 N	.....	+6	− 1	− 2
18	17 53 S	281 43	11.0 E	....	.....	0.6 E	0.0	0.1W	.....	.....	.....
19	16 48 S	281 50	10.8 E	....	.....	0.7 E	0.1 E	0.1 E	.....	.....	.....
19	16 16 S	281 53	....	8.7 S	.294	0.8 N	3.7 N	.....	+6	− 2	− 2
19	16 04 S	281 55	10.2 E	....	.....	0.3 E	0.2W	0.3W	.....	.....	.....
20	14 48 S	282 07	9.9 E	....	.....	0.4 E	0.1W	0.0	.....	.....	.....
20	14 09 S	282 10	....	5.2 S	.296	1.1 N	3.8 N	.....	+4	− 4	− 4
20	14 01 S	282 11	9.6 E	....	.....	0.4 E	0.0	0.0	.....	.....	.....
21	13 34 S	282 22	9.6 E	....	.....	0.5 E	0.2 E	0.2 E	.....	.....	.....
21	13 05 S	282 38	....	2.8 S	.298	1.7 N	3.9 N	.....	+4	− 3	− 4
21	12 57 S	282 38	9.2 E	....	.....	0.4 E	0.1 E	0.0	.....	.....	.....
22	12 17 S	282 36	....	1.3 S	.299	1.9 N	4.6 N	.....	+3	− 5	− 5

Date	Latitude	Long. East of Gr.	Carnegie Values			Chart Differences[2]					
						Decl'n and Incl'n			Hor. Int.[3]		
			Decl'n	Incl'n	Hor. Int.	Brit.	Ger.	U. S.	Brit.	Ger.	U. S.
1918	° ′	° ′	°	°	c.g.s.	°	°	°			
Mar. 29	11 53 S	282 32	....	0.4 S	.299	2.5 N	4.6 N	.....	+2	− 5	− 6
29	11 42 S	282 19	8.6 E	....	.....	0.0	0.8W	0.2W	.....	.....	.....
30	11 06 S	281 41	8.8 E	....	.....	0.1 E	0.6W	0.1 E	.....	.....	.....
30	10 56 S	281 19	....	0.3 N	.303	1.6 N	4.4 N	.....	+2	− 5	− 7
30	10 49 S	281 06	9.0 E	....	.....	0.2 E	0.6W	0.3 E	.....	.....	.....
31	10 14 S	280 02	9.0 E	....	.....	0.1 E	0.6W	0.2 E	.....	.....	.....
31	9 58 S	279 12	....	1.3 N	.309	2.3 N	4.6 N	.....	+4	− 5	− 7
31	9 57 S	278 52	9.2 E	....	.....	0.0	0.5W	0.0	.....	.....	.....
Apr. 1	10 01 S	277 43	9.3 E	....	.....	0.1W	0.7W	0.1W	.....	.....	.....
1	10 19 S	277 01	....	0.5 S	.310	1.3 N	4.3 N	.....	+3	− 6	− 8
1	10 25 S	276 45	9.9 E	....	.....	0.2 E	0.3W	0.2 E	.....	.....	.....
2	11 09 S	275 26	10.2 E	....	.....	0.2 E	0.5W	0.1 E	.....	.....	.....
2	11 28 S	274 50	....	3.8 S	.310	0.1 S	3.7 N	.....	+3	− 6	− 8
2	11 32 S	274 41	10.3 E	....	.....	0.1 E	0.8W	0.0	.....	.....	.....
3	12 07 S	273 46	10.6 E	....	.....	0.2 E	0.9W	0.1 E	.....	.....	.....
3	12 10 S	273 42	10.6 E	....	.....	0.2 E	0.9W	0.1 E	.....	.....	.....
3	12 33 S	273 11	....	6.6 S	.310	1.6 S	4.0 N	.....	+4	− 5	− 8
3	12 43 S	272 59	10.8 E	....	.....	0.2 E	0.9W	0.1 E	.....	.....	.....
4	13 47 S	271 38	11.2 E	....	.....	0.2 E	1.1W	0.2 E	.....	.....	.....
4	14 23 S	270 50	....	11.1 S	.306	3.1 S	3.5 N	.....	+2	− 8	−10
5	15 38 S	269 18	11.8 E	....	.....	0.2 E	1.1W	0.3 E	.....	.....	.....
5	16 13 S	268 34	....	15.7 S	.305	4.7 S	2.5 N	.....	+2	− 6	− 8
5	16 16 S	268 30	12.2 E	....	.....	0.4 E	1.3W	0.4 E	.....	.....	.....
6	16 13 S	266 53	11.9 E	....	.....	0.1 E	1.6W	0.2 E	.....	.....	.....
6	16 05 S	266 05	....	16.5 S	.306	5.0 S	2.7 N	.....	0	− 8	−10
6	15 59 S	265 45	11.8 E	....	.....	0.0	1.6W	0.1 E	.....	.....	.....
7	15 36 S	263 38	11.4 E	....	.....	0.3W	1.8W	0.1W	.....	.....	.....
7	15 25 S	263 22	....	16.6 S	.310	5.9 S	2.2 N	.....	0	− 8	−10
7	15 02 S	263 19	11.8 E	....	.....	0.3 E	1.1W	0.5 E	.....	.....	.....
8	14 02 S	264 04	11.4 E	....	.....	0.1 E	1.2W	0.3 E	.....	.....	.....
8	13 32 S	264 20	....	12.8 S	.312	5.1 S	2.6 N	.....	−2	−10	−12
8	13 18 S	264 30	11.6 E	....	.....	0.5 E	0.8W	0.6 E	.....	.....	.....
9	12 25 S	264 52	11.1 E	....	.....	0.2 E	1.0W	0.4 E	.....	.....	.....
9	11 59 S	265 04	....	9.4 S	.316	3.8 S	3.1 N	.....	−1	− 9	−10
9	11 48 S	265 10	11.3 E	....	.....	0.5 E	0.6W	0.7 E	.....	.....	.....
10	10 53 S	265 45	10.7 E	....	.....	0.1 E	0.9W	0.3 E	.....	.....	.....
10	10 28 S	266 06	....	6.4 S	.318	3.2 S	3.5 N	.....	−1	− 9	−11
10	10 16 S	266 14	10.9 E	....	.....	0.5 E	0.5W	0.6 E	.....	.....	.....
11	9 14 S	267 00	10.6 E	....	.....	0.4 E	0.4W	0.5 E	.....	.....	.....
11	9 08 S	267 05	10.7 E	....	.....	0.5 E	0.2W	0.7 E	.....	.....	.....
11	8 36 S	267 33	....	2.0 S	.321	1.4 S	3.7 N	.....	−1	− 9	−11
11	8 24 S	267 44	10.6 E	....	.....	0.6 E	0.2W	0.6 E	.....	.....	.....
12	7 43 S	268 30	10.0 E	....	.....	0.2 E	0.5W	0.1 E	.....	.....	.....
12	7 21 S	268 53	....	1.0 N	.322	0.0	3.8 N	.....	0	− 9	−12
12	7 13 S	269 00	10.3 E	....	.....	0.6 E	0.0	0.4 E	.....	.....	.....
13	6 31 S	269 47	9.7 E	....	.....	0.1 E	0.3W	0.0	.....	.....	.....
13	6 17 S	270 07	....	3.9 N	.324	0.7 N	3.9 N	.....	+1	− 7	−11
13	6 14 S	270 12	9.9 E	....	.....	0.4 E	0.1W	0.2 E	.....	.....	.....
14	5 38 S	271 28	9.7 E	....	.....	0.4 E	0.1W	0.2 E	.....	.....	.....
14	5 08 S	272 14	....	7.1 N	.323	1.3 N	4.3 N	.....	0	− 8	−12
14	5 00 S	272 22	9.3 E	....	.....	0.1 E	0.1W	0.0	.....	.....	.....
14	4 52 S	272 31	9.3 E	....	.....	0.1 E	0.1W	0.0	.....	.....	.....

Date	Latitude	Long. East of of Gr.	Carnegie Values			Chart Differences[2]					
						Decl'n and Incl'n			Hor. Int.[3]		
			Decl'n	Incl'n	Hor. Int.	Brit.	Ger.	U. S.	Brit.	Ger.	U. S.
1918	° ′	° ′	°	°	c.g.s.	°	°	°			
Apr. 15	3 54 S	273 33	9.0 E	....	.....	0.1 E	0.1 E	0.1W	.....	.....	.....
15	3 25 S	273 42	....	11.0 N	.324	2.2 N	4.6 N	.....	−2	− 8	−13
15	3 12 S	273 45	8.7 E	....	.....	0.0	0.0	0.2W	.....	.....	.....
16	2 22 S	274 14	8.5 E	....	.....	0.1 E	0.1 E	0.0	.....	.....	.....
16	1 57 S	274 32	....	14.5 N	.325	3.3 N	5.4 N	.....	−3	− 7	−14
16	1 49 S	274 36	8.3 E	....	.....	0.1 E	0.1 E	0.0	.....	.....	.....
17	1 27 S	275 04	8.2 E	....	.....	0.2 E	0.2 E	0.1 E	.....	.....	.....
17	1 04 S	275 27	....	16.5 N	.326	3.5 N	5.2 N	.....	−3	− 6	−14
17	0 56 S	275 37	7.9 E	....	.....	0.1 E	0.0	0.1W	.....	.....	.....
18	0 04 S	276 27	7.7 E	....	.....	0.3 E	0.1 E	0.2 E	.....	.....	.....
18	0 17 N	277 06	....	19.8 N	.326	3.8 N	5.5 N	.....	−3	− 6	−14
18	0 23 N	277 20	7.2 E	....	.....	0.2 E	0.1W	0.1 E	.....	.....	.....
19	1 22 N	278 08	6.9 E	....	.....	0.2 E	0.1W	0.2 E	.....	.....	.....
19	1 48 N	278 35	....	23.0 N	.323	3.9 N	5.2 N	.....	−7	− 9	−17
19	1 55 N	278 44	6.7 E	....	.....	0.3 E	0.1W	0.1 E	.....	.....	.....
20	2 24 N	279 49	6.1 E	....	.....	0.1 E	0.5W	0.0	.....	.....	.....
20	2 32 N	280 03	....	24.8 N	.324	3.8 N	5.2 N	.....	−4	− 7	−14
20	2 40 N	280 09	5.9 E	....	.....	0.0	0.4W	0.1 E	.....	.....	.....
21	3 07 N	280 32	5.9 E	....	.....	0.2 E	0.3W	0.2 E	.....	.....	.....
21	3 36 N	280 45	....	27.1 N	.324	4.3 N	4.9 N	.....	−5	− 7	−14
21	3 47 N	280 49	5.7 E	....	.....	0.1 E	0.3W	0.3 E	.....	.....	.....
22	4 29 N	281 18	5.3 E	....	.....	0.0	0.5W	0.1 E	.....	.....	.....
22	5 19 N	281 31	....	30.3 N	.322	4.4 N	4.6 N	.....	−7	− 8	−15
23	6 40 N	281 41	4.4 E	....	.....	0.4W	0.8W	0.2W	.....	.....	.....
23	7 20 N	281 36	....	33.7 N	.322	4.3 N	4.5 N	.....	− 8	− 8	−16
24	7 57 N	280 38	4.9 E	....	.....	0.1 E	0.1W	0.3 E	.....	.....	.....

A STUDY OF PRESSURE AND TEMPERATURE EFFECTS IN EARTH-CURRENT MEASUREMENTS.

By S. J. Mauchly.*

Introduction.

A large portion of the earth-current data now available is based upon observations made on commercial telegraph lines. During times of abnormal activity, the horizontal potential-gradient frequently assumes values of the order of 0.5 volt per kilometer, and sometimes exceeds ten times this value. For earth-current measurements made during such periods and also for extended series of measurements made on lines of great length, the difference of potential between the terminals is so great that most of the variations due to local causes at the earth-plates may safely be assumed to play only a minor part in the production of the observed phenomena.

However, partly because of the fact that commercial lines can, at best, be available only part of the time for scientific observations, and partly because of the desirability of controlling such matters as the location of lines, nature of earth-plates, etc , it is preferable, wherever possible, to install special lines for earth-current measurements. Geological conditions, as well as financial and other considerations, usually make it necessary or at least desirable to limit the length of such special lines. When this is done we are no longer justified in making the assumption referred to above, and it becomes desirable to investigate the relation between the total variations observed and those due to local causes. The general nature of the various components of the current measured on short lines has been well set forth by Chree[1] and by Nippoldt.[2] The experiments to be described were carried out with a view of determining more definitely the nature and order of magnitude of some of these spurious effects.

It is well known that variations in the moisture and temperature of the soil in contact with the plate terminals of an earth-current line produce corresponding variations in the E. M. F. of the pri-

* Report on special earth-current investigations made at the laboratory of the Department of Terrestrial Magnetism at Washington, 1916-1917, preparatory to the inauguration of earth-current observations at the observatories to be established by the Department. A paper on the subject was presented before the Philosophical Society of Washington, April 13, 1918

mary cell consisting of the two earth-plates and the intervening soil. To eliminate effects due to both these causes, the plates are usually buried at a considerable depth, so that the conditions may be assumed fairly constant, at least so far as the diurnal variation is concerned. But when the lines connect points at considerable difference of elevation this procedure obviously cannot eliminate the effect just mentioned unless the plates are buried much deeper than is customary.

Attention has several times been directed to relatively large currents between plates buried at different depths.[3] Since the general existence of a vertical earth-current density of an order of magnitude much larger than the atmospheric-electric current density seems inconsistent with the principle of continuity of flow of electricity, it seemed desirable to attack first the problem of determining whether much of the so-called vertical-current density was not a phenomenon which owed its origin to spurious causes, such, for example, as those arising from differential pressure-effects and temperature effects at the electrodes. The first part of the paper is devoted to the results of laboratory experiments dealing mainly with a pressure effect, while the second part is based on out-of-door measurements dealing with temperature effects.

PART I —LABORATORY EXPERIMENTS RELATING TO THE ELECTROMOTIVE FORCE ASSOCIATED WITH A DIFFERENCE IN PRESSURE BETWEEN TWO EARTH-PLATES.

A glass tube 150 cm. long and 5 cm. internal diameter was filled with freshly-dug, rather sandy, soil of uniform composition, and one of two similar (amalgamated zinc) electrodes imbedded in the soil near each end, the tube being vertical. As is to be expected, when these electrodes are connected to a sensitive galvanometer, a current is indicated; but if any portion of the E. M. F. owes its origin to pressure-difference at the two electrodes, this portion may be expected to reverse its direction relative to the tube when the tube is inverted, similar to the effect observed in salt solutions by Des Coudres[4] and others. With a tube of smooth interior such as the one just described, pressure adjustments take place readily

[1] CHREE, C., *Encyclopædia Britannica*, Eleventh Edition, v. 8, pp. 813-816.

[2] NIPPOLDT, A., *Müller-Pouillets Lehrbuch der Physik*, 1914, pp. 1458-1459; *Met. Zs., Braunschweig*, 28, 1911, pp. 244-261.

[3] Among others may be cited the following: JAHR, E., Untersuchungs Ergebnisse über den natürlichen elektrischen Erdstrom, *Elektrot. Zs., Berlin*, v. 23, 1902, pp. 196-197; BRUNHES, B., Sur les courants telluriques, *Paris, C.-R. Acad. Sci.*, v. 151, Aug. 1, 1910, pp. 409-411.

under the action of gravity, provided the soil is not too moist. It was found that the E. M. F. between the two ends of the tube showed a component which reversed its direction when the tube was inverted, and which, if acting alone, would cause the lower end of the tube to function as its cathode. The E M. F.'s were measured by means of a balance method, readings being taken at intervals of about two minutes, which was the time required for inverting the tube, securing a balance, and recording the result.

Table 1 gives the results of a set of such observations, the same electrode, designated as *A*, being positive throughout:

Table 1.

Time	Position of *A*	E. M. F.
h m		*volt*
9 30	Up	0.028
	Down	0.077
	Up	0.038
	Down	0.045
	Up	0.006
	Down	0.036
9 45	Up	0.033

This gives a mean of 0.053 volt for the total E. M. F. when the positive end is down, and 0.026 volt when the positive end is up, which corresponds to a mean value of 0.014 volt for a component of the E. M. F. having a reversible direction relative to the tube, or, in other words, a constant direction relative to the difference of pressure between the two electrodes.

Experiments were made with several other tubes and with various pairs of electrodes, but always with results similar to the above. As was to be expected, the mean value of the reversible effect for a set of readings, depending as it did upon various factors, did not remain constant from day to day, even for the same length electrodes. These mean values ranged for different conditions from 1 to 23 millivolts in tubes about 150 cm. long, although most of them were between 10 and 15 millivolts Only when the soil was too dry, or when it was too wet to flow properly, was there any absence of consistent results Occasionally the non-reversible component of the E. M. F. was smaller than the reversible component, in which case the total observed E M. F. consistently

[4] Des Coudres, *Ann. Physik, Leipzig*, v. 55, 1895, p. 213.

showed its cathode to be at the lower plate. This, however, was not usually the case with tubes containing soil only, and is not to be regarded as typical.

In general, the reversible E. M. F. increased with the degree of moisture so long as the soil was not too moist for successful operation. All the tubes showed used considerable variations in total E. M. F. with variations in the difference between the temperatures at the two electrodes. This variation was always such that the electrode whose temperature was increasing relative to the other tended also to become positive with regard to the other.

Materially increasing the length of the tube in order to observe directly the effect of increased pressure difference was not feasible because of the attendant increase in operating difficulties. In order, however, to obtain some evidence along this line the plan was adopted of employing a much stronger and somewhat larger tube in which an increased difference of pressure could be secured by the insertion of a heavy brass cylinder midway between the electrodes Observations made with and without the cylinder are, of course, not strictly comparable. This is partly due to the impossibility of reproducing the initial conditions at the main electrodes after introducing the cylinder and partly to the possible introduction of differential effects at the upper and lower faces of the cylinder. While it is not possible to separate these component effects, it is interesting to note that in both cases (using different cylinders) where this procedure was followed there was such a large increase in the reversible component of the total E. M. F. that the lower electrode was always positive, regardless of which end of the tube was at the bottom. The data in Table 2 were obtained by using a bituminized fiber tube of 150 cm. length and 7 cm. inside diameter. The electrodes were zinc cylinders 6 cm. in length and 3.5 cm high. Each electrode had its surface cleaned by filing, and was imbedded in the soil about 15 cm. from one of the ends. The brass cylinder used was 35 cm. long and 6 cm. in diameter. The soil had been sifted to secure uniformity of composition and moisture.

Before the introduction of the cylinder the *end A* remained positive throughout, and the mean reversible component was only 0 003 volt; after the cylinder was introduced the *lower end* was always positive, and the mean reversible component was 0.102 volt. Experiments were made on the following day, using a different cylinder, gave similar results. It appears probable, therefore,

that an increase in pressure difference is accompanied by an increase in the associated E. M. F., although the data obtained are inadequate for the determination of the connecting relation.

Table 2.

Time	End down	End positive	E. M. F.	Remarks
h m			*volt*	
14 43	A	A	0.0210	Soil only in tube.
45	B	A	.0180	" " " "
47	A	A	.0375	" " " "
48	B	A	.0300	" " " "
50	A	A	.0390	" " " "
51	B	A	.0315	" " " "
15 53	A	A	.0360	" " " "
55	B	A	.0300	" " " "
16 16	A	A	.0375	" " " "
18	B	A	.0300	" " " "
21	A	A	.0360	" " " "
30	A	A	.0750	Brass cylinder in middle of tube.
32	B	B	.1500	" " " " " "
36	A	A	.0068	" " " " " "
38	B	B	.1650	" " " " " "
40	A	A	.0600	" " " " " "

In addition to the experiments with earth-filled tubes, some measurements were also made on tubes filled with salt water. For the salt-water solutions the observed values of the reversible E. M. F., based on readings taken immediately after inversion, are in good agreement with those obtained by Des Coudres.

Conclusions (*Part I*).

It has been shown that in a cell consisting of a non-conducting vertical tube filled with moist soil and supplied with a metal electrode near each end, there exists a component of the total E. M. F. whose direction tends to establish a cathode at the lower electrode regardless of the orientation of the tube; i. e., the electrode under greater pressure tends always to be positive with regard to the other one.

The magnitude of the effect varied with the nature of the electrodes and soil, but was always much in excess of the effects observed in simple salt solutions by Des Coudres. It is probable that the theoretical basis in the present case is not the same as that investigated by him.

Apparently the E. M. F. associated with difference of pressure at the electrodes increases with increased pressure-difference, although the law of variation is not known.

From the standpoint of earth-current measurements the important features to be noted are as follows:

1. If the effect observed is representative of a general pressure-effect, it is of the order of magnitude necessary to account for the potential differences which have been found by various observers to be associated with vertical earth-currents.

2. The electrode at greater depth would by the operation of this effect tend to be permanently positive toward the upper one This is in agreement with many recorded observations.

3. It is obvious that such an effect could not give rise to annual and diurnal variations. It is of interest in this connection to note that some observers have commented on the constancy of the vertical earth-currents which they observed, while others have called attention to the smallness of the diurnal variation of such currents.

Part II.—Out-of-Door Experiments on the Relation Between Temperature Difference and Plate E. M. F. for a Given Pair of Earth-Plates, and Its Bearing on Measurements of the Vertical Earth-Current.

As indicated in Part I, the electrodes used in the laboratory experiments for investigating the effect of pressure difference at the electrodes showed that a marked relation existed between temperature difference and E M. F. It was decided to study this relation under conditions of temperature and moisture such as hold in actual earth-current measurements. The general plan was to secure, by means of automatic recording devices, continuous records showing the simultaneous variations in temperature difference and E. M F. between two earth-plates buried at different depths. In order to secure a rather large variation in temperature difference, one of the plates was buried near the surface, where both the diurnal and seasonal changes are large, and the other in the same vertical line, but at a depth corresponding to relatively small temperature fluctuations. The influence of natural earth-currents and industrial strays upon the recorded E. M. F. was eliminated by enclosing both these plates in a vertical cylinder of insulating material. For comparison purposes, continuous records

were also obtained showing the variation in potential difference between a second pair of plates similar to the first and similarly located, except that they were *outside* of the insulating cylinder containing the other circuit. The two vertical circuits were located about 6 ft. west of Observing House *A* of the Department of Terrestrial Magnetism, at Washington, in order that this structure could be used as a shelter for the recording and calibrating systems.

Owing to the great variations of temperature to which all the apparatus was necessarily subjected, measurements of great precision would have been difficult to obtain, had they been desirable. Since the results of refined and highly accurate measurements would in this case serve no useful end, being strictly applicable to the present installation only, the choice of apparatus and method was made with a view to securing only such a degree of accuracy as would be generally useful in the consideration of earth-current measurements.

The general arrangement of the underground systems is shown in Fig. 1. E_1 and E_2 are zinc earth-plates forming the electrodes of the insulated circuit, P_1 and P_2 the electrodes of the non-insulated comparison circuit, and T_1 and T_2 platinum resistance-thermometers located midway between the two upper and the two lower electrodes, respectively. The two circuits were about 45 cm apart.

The insulating tube was made by filling with molten pitch the annular space between two strong coaxial pasteboard cylinders. The inner and outer surfaces of the tube were also covered with an application of hot pitch. The lead wire from E_2 was carried up to the surface between the two pasteboard cylinders. The length of the tube was 225 cm., and its average inside diameter was 20 cm The average thickness of pitch between the pasteboard cylinders was 2 cm. The insulation provided by this tube proved to be entirely satisfactory throughout the period of its use.[5] The tube as installed projected about 10 cm. above the surface of the ground, the level of which was the same in the tube as outside. E_1 was 25 cm below the surface, and E_2 about 10 cm. from the lower end of the tube. At the time of installation the distance

[5] For two months prior to the installation of the tube described above, the plates E_1 and E_2 were inclosed in a pitch-coated tube of bituminized fiber 210 cm. long and 7 cm. inside diameter. This tube provided fair insulation, but owing to its small cross-section, the resistance of the insulated circuit was so high as to prevent its recording system from being operated at the desired sensitivity. With the new tube, installed in November, 1916, ample sensitivity was never lacking. The change to the new tube was not accompanied by any appreciable change in the phenomenon under observation.

between the level of the upper and lower electrodes was 180 cm. for each circuit.

All the leads consisted of suitable copper wires covered with a high-grade of water-proof insulation, which had been subjected to a thorough under-water test.

All the soil excavated in connection with the installation of the underground systems was of rather uniform composition, consisting of clay with a considerable admixture of finely-divided mica. On its replacement, the soil was well tamped, care being taken to have the greatest possible uniformity in the soil surrounding the four electrodes.

Inasmuch as no drainage could be provided for the tube, it was desirable that this should receive much less rain than the surrounding soil. A ventilated hood was therefore used to protect it from excessive rain and snow, although an attempt was made to counteract the effect of evaporation by occasionally allowing the tube to remain uncovered during a shower. During fair weather the tube was not covered, in order to secure a fair degree of uniformity in regard to insulation and evaporation at the surface of the soil above the two circuits. The effect of unequal moisture conditions in the two circuits will be again referred to in the discussion of results.

The platinum thermometers T_1 and T_2 had a fundamental interval of about 1.5 ohm each. They were inclosed in thin-walled glass tubes, which in turn were protected by rather closely-fitting brass tubes provided with water-tight sealing chambers for introducing the leads. Precautions were taken to have the thermometer tubes free from moisture before they were sealed into the brass tube, in order to prevent condensation effects during periods of low temperature. The thermometers were provided with compensating leads and used in connection with a manganin bridge of Callendar and Griffith's pattern, each thermometer being in series with the compensating leads of the other. The system was calibrated to give temperature differences directly, 15 mm. on the bridge wire corresponding to a temperature difference of 1°.0 C. While this limited the determination of daily base-values to an accuracy of about 0°.01 C., departures from these base values, resulting from the dirunal variation, would have been obtainable to a much greater precision had they been desired. For our present purpose, however, we are mostly concerned with relative values throughout the day, and since the photographic records were only

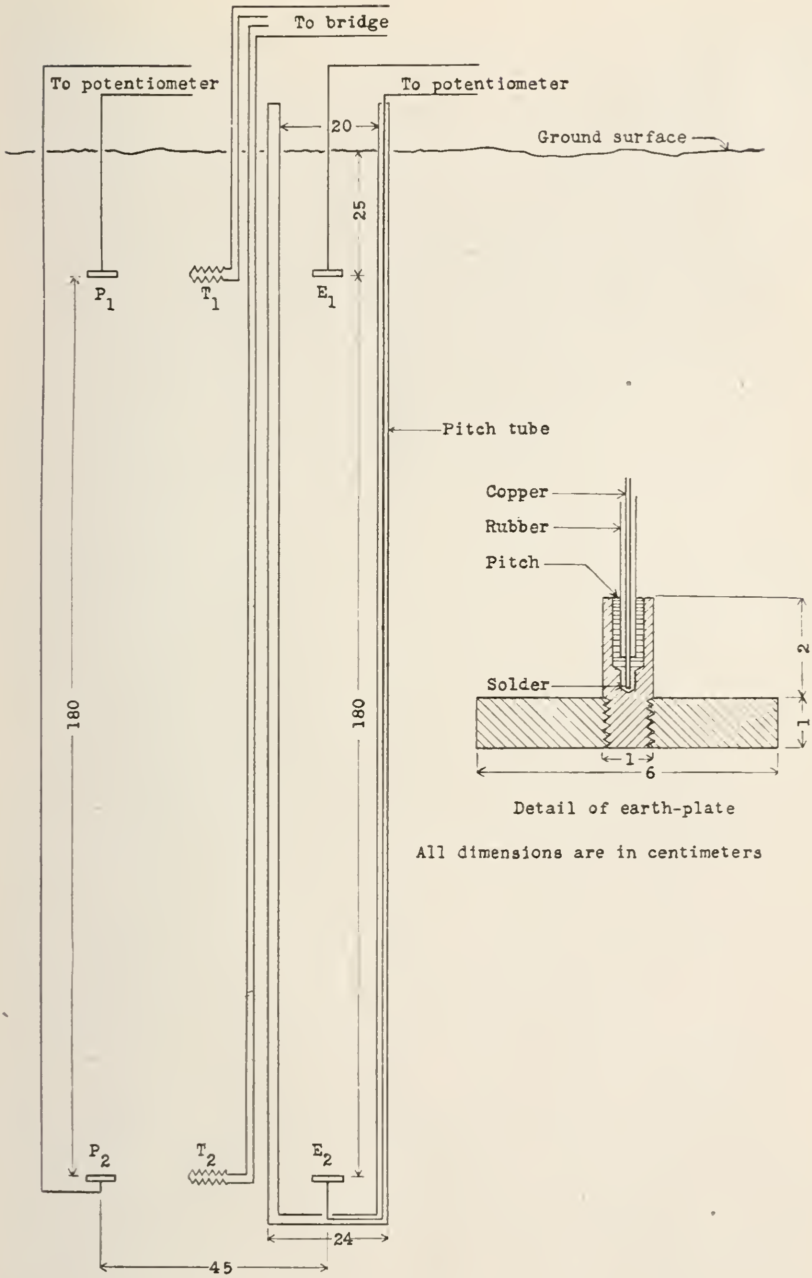
To bridge
To potentiometer
To potentiometer
20
Ground surface
25
P1
T1
E1
Pitch tube
Copper
Rubber
Pitch
2
Solder
1
1
6
Detail of earth-plate
All dimensions are in centimeters
180
180
P2
T2
E2
24
45

FIG. 1.

19 cm. in width, while the change in temperature difference was sometimes as great as 2 or 3 degrees during 24 hours, it is obvious that a high sensitivity was undesirable. The average sensitivity employed was such that a change of 1°.0 C. in temperature difference corresponded to a 50 mm. change in deflection on the photographic record. While it was nearly always possible, in scaling values from the traces, to determine departures from the base value with an accuracy of about 0°.002 C., these values were rounded off to the nearest 0°.01 for recording.

In the preparation of the earth-plates the aim was to secure as great a similarity as possible between the corresponding electrodes of the two circuits to facilitate comparison of results. The two upper electrodes E_1 and P_1 were formed from the two halves of a zinc cylinder about 3 cm. high and 6.5 cm. diameter, while E_2 and P_2 were similarly obtained from a second cylinder of the same dimensions. Each of the plates was turned to size and provided with a special tube enclosing the connection to its lead, as shown in the detail of Fig. 1. Considerable care was taken to have uniformity of process and of heat treatment while making the solder joints between the copper wires and the zinc connecting tubes. One end of each of the four copper leads was bared and carefully tinned, the rubber insulation being wrapped with a wet cloth during the operation. A small amount of soft solder and a bit of rosin was dropped into the receptacle indicated in Fig. 1, after which the connecting tube was carefully heated on a hot metal plate. As soon as the solder was melted, the tinned end of one of the wires was introduced into it and the connecting tube cooled in water to prevent unnecessary heating of the insulation. The space between the rubber insulation and the surrounding tube was filled with pitch, the metal tube being set in a shallow pan of boiling water until the pitch was all melted. Usually pitch had to be added several times before the tube was filled. After cleaning the surfaces of the connecting tube and electrode, the parts were assembled and amalgamated.

The leads associated with each of the earth-plate circuits were connected to one of two high-resistance potentiometers, one lead passing directly to the potentiometer and the other making its connection through a sensitive moving-coil galvanometer. The advantage of using potentiometers for these measurements is apparent when one considers the question of polarization of the earth-plates. With potentiometers adjusted for balance there

would of course be no polarization; further, with a base-value approximately equal to the mean potential difference (P. D.) for the day, the current in a given circuit would be very near zero for much of the time, and would in general reverse its direction several times during the day. There was in fact at no time any evidence of polarization in either circuit.

Continuous records were obtained by the photographic method, using a recording drum driven by clockwork. The record sheets were 19 cm. wide and 40 cm long, all three traces for a given day being recorded on a single sheet. As already stated, it was found necessary to limit the recording sensitivity of the thermometer system to about 0°.02 per mm. to keep the spot of light on the recording sheet. For like reason the average recording sensitivity of the other two systems was about 5×10^{-5} volt per mm.[6] The base values for each of the earth-plate systems could be determined with an accuracy of 1.0×10^{-4} volt.

Time indications and base lines were obtained hourly by short-circuiting the terminals of each galvanometer. This was effected by means of a clock arranged to operate mercury-contact shunts. Frequent tests showed that with proper care no spurious effects of appreciable magnitude were introduced by this procedure. It was adequate for the purpose of the work in hand to obtain from the traces, at intervals of one hour, the approximately simultaneous values of the elements under observation. The possibility of errors due to wandering of galvanometer zeros was eliminated by scaling the hourly values corresponding to the time of the hourly zero record. Base values were adjusted and sensitivities determined daily.

The observations were continued without serious interruption from September, 1916, to May, 1917. During the winter months the temperature variations were naturally very irregular and not well suited for automatic registration, because of the great extremes which caused frequent departures of one or more of the recording spots from the photographic record. It was considered worth while, however, to continue the registration to obtain data regarding certain conditions which are peculiar to the season, as, for example, the effect of a layer of snow over the soil and the effect of frozen soil at the upper electrode. When observations were begun in September and again when they were discontinued in

[6] The accuracy attainable in scaling the P. D. traces was about 1.0×10^{-5} volt for the insulated circuit, and 1.0×10^{-4} volt for the other one. In both cases the values were tabulated to the nearest 0.0001 volt.

May, the temperature at the upper thermometer was several degrees higher than at the lower one, while the extreme reverse condition was reached on February 13, 1917, when the temperature at the lower thermometer was in excess by 14°.6 C. These figures give an idea of the seasonal variations upon which the observed diurnal variations were superposed. During the winter there was, as stated above, no *regular* diurnal variation, the temperature difference sometimes remaining almost constant for days, when the ground was covered with snow, and at other times, in the absence of snow, undergoing large but irregular fluctuations. Because of their opposed seasonal variations and because of their similarity in all other respects, the autumn and spring values only were used in the preparation of the mean diurnal-variation curves shown in Fig. 2. Results were included only from those days on which the records were complete for all three elements or could be made complete by a small amount of justifiable interpolation. On this basis of selection the number of days available for computation of the mean hourly values represented in Fig. 2 was limited to 87.

Curves A, B, and C, of Fig. 2 represent, respectively, temperature at upper thermometer minus the temperature at lower thermometer, P. D. between the terminals E_1 and E_2 of the insulated circuit, E_1 being positive, and P. D. between the terminals P_1 and P_2 of the non-insulated comparison circuit, P_1 being positive. During the last two months of the observation period, unfortunately some errors were introduced into the temperature-difference records, due to a short piece of iron pipe which had been driven into the soil not very far from the upper thermometer for the purpose of making some auxiliary measurements with a mercury thermometer. Comparison of the curves obtained with this pipe in position with similar curves obtained in absence of the pipe showed that its effect was negligible except during the hours of intense sunshine. Further, the curve representing the mean hourly values of the air temperature in Observing House A, obtained from thermograph records, is everywhere similar to curve A (if we take account of the difference in phase), except between the hours of 8 and 16. The dotted portion of curve A, therefore, was drawn in conformity with the shape of the mean air-temperature curve, taking account of lag, and the mean temperature-difference curve for days when the disturbing pipe was not in position.

From a comparison of curves A and B of Fig. 2 we see that

for the insulated circuit there was a very close agreement between the variations in temperature difference and P. D., and that a change of 1°.0 C. in temperature difference was accompanied, on the average, by a change of about 1 millivolt in P. D. It is seen also that the direction of the effect is such that increasing the temperature of the upper plate with regard to the lower one causes

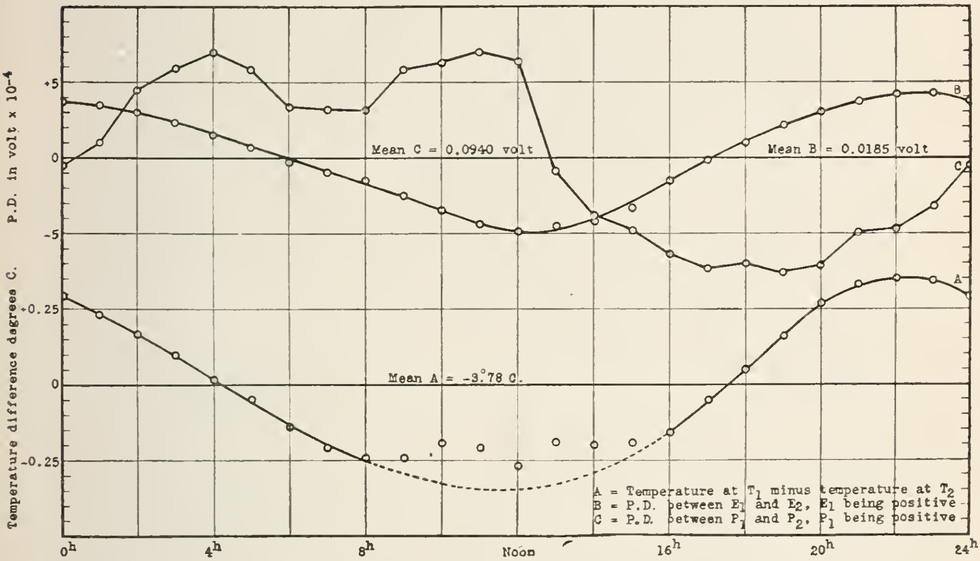

Fig. 2.

the upper plate to become increasingly positive with regard to the lower one This is in agreement with the qualitative results obtained in the laboratory and referred to in Part I. Curve C of Fig. 2, on the other hand, has an amplitude twice as large as that of *B*, and shows no similarity to curves *A* or *B*, unless one assumes a very large difference in phase. We evidently cannot look to the thermal effect which is so obvious in curve *B*, to explain curve *C*. It should be stated that in one respect the records for the two earth-plate circuits always showed a marked difference, the trace represented by *B* being always a relatively smooth curve, while that represented by *C* was never free from small fluctuations, except between the hours of 2 and 5. Inasmuch as most of the electric-railway lines in the District of Columbia are not grounded, and since the line of the Chevy Chase Electric Railway, only 0.5 mile (800 meters) distant, is one of the few outlying lines using

the track as a return, it was thought that a study of the load conditions prevailing on this line might be instructive. Through the kindness of the officials of the Capital Traction Company, it was possible to obtain access to the records of the desired data. Curve A, Fig. 3, shows the mean value of the railway's load in amperes for each hour of the day, over a period of 14 days. Curve B corresponds to the mean hourly values of the P. D. between P_1 and P_2 for the same 14 days. While consistent mean curves cannot be expected from so short a period as 14 days, the two curves do nevertheless show evidence of a very close relation. Curve C of Fig. 3 is the same as Curve C of Fig. 2, namely, the 87-day mean curve for P. D. between P_1 and P_2. If this curve were corrected for temperature effects and plotted against the corresponding 87-day mean load curve, we would probably find most if not all of its diurnal variation accounted for. Although the railway data are not now in hand for making such a comparison, the conclusion seems warranted, nevertheless, that nearly all of the observed diurnal variation between the two earth-plates P_1 and P_2 was due to variations in temperature difference and to stray currents from the nearby electric railway.

All the observations suitable for discussion divide themselves naturally into two groups, namely, those in which the temperature at the upper thermometer was above —1°.0 C. and those for which

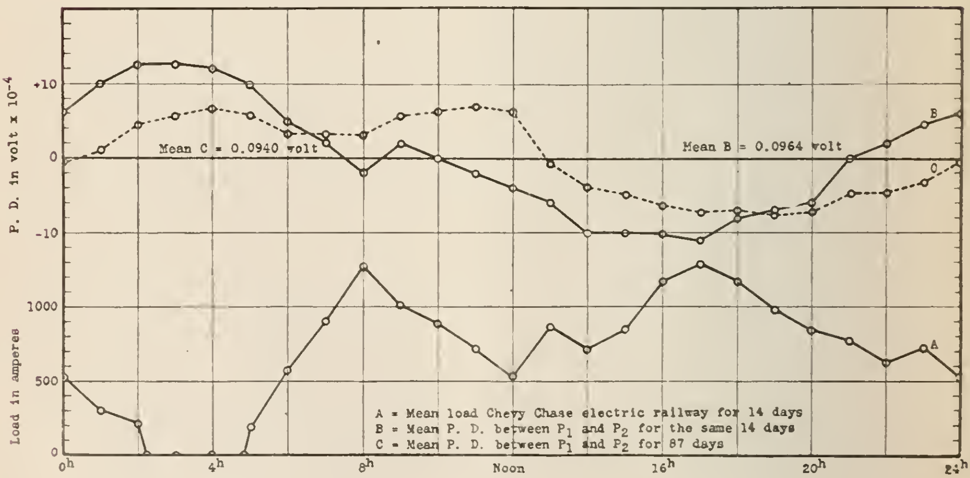

FIG. 3.

it was below —2°.0 C. All the curves thus far shown belong to the first class.

During most of February, 1917, there was little or no snow on the ground where the observations were carried out. At a temperature of somewhere between —1°.0 and —2°.0 C. the soil at the upper electrode became frozen and remained in this condi-

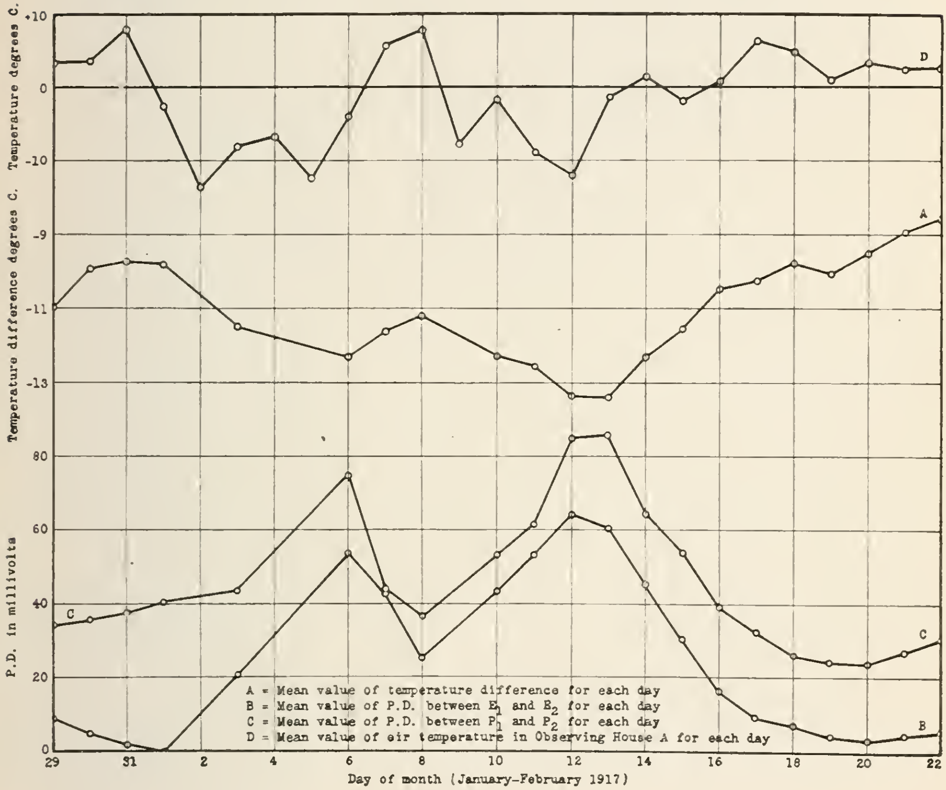

Fig. 4.

tion for several weeks. Throughout the period during which the temperature at the upper thermometer was below —2°.0 C. the temperature effect was between 15 and 20 times as large as that found to prevail in autumn and spring. Furthermore, the sign of the effect was reversed. In other words, before January 25 and after February 25 a 1°.0 *increase* of temperature at the upper electrodes relative to the lower ones was accompanied by an *increase* of 1 millivolt in P. D., the upper plates becoming *more*

positive with regard to the lower ones; while between February 1 and 19 a relative temperature *increase* of 1°.0 at the upper electrodes corresponded to a *decrease* of 15 to 20 millivolts in P. D., the upper plates becoming relatively *less* positive. The pronounced difference between the two cases is well shown by a comparison of Figs. 4 and 5. In Fig. 4 we have for each of the elements the mean values for each day (except for several days when records were incomplete), for the period January 29 to February 22, 1917, the system used in plotting being the same for Figs. 4 and 5 as was used in Figs. 2 and 3. A glance at the curves shows that the P. D. curves *B* and *C*, corresponding to the insulated and non-insulated circuits, respectively, are here very similar and run parallel courses, but are both opposed in curvature to the corresponding temperature-difference curve *A*. These characteristics were as clearly marked on the daily traces as in the means here shown. The reason for similarity between *B* and *C* on daily traces for this period is of course the fact that the amplitude of the total P. D. changes was so great that the effect of electric-railway strays was small in comparison. It has been stated that a change of 1°.0 in temperature difference corresponded under the present conditions to a change of 15 to 20 millivolts. This relation is substantially the same whether obtained from the continuous record for a single day or from the mean values corresponding to individual days as given in Fig. 4. Curve *D*, representing the mean air temperature in Observing House *A*, for the period corresponding to the other curves, is added to show the relation between the atmospheric temperature changes and the other elements under consideration.

The possibility of any appreciable part of the effects just described having been due to temperature effects on the LeClanche cells associated with the potentiometers was investigated in the laboratory at the conclusion of the out-of-door observations. The E. M. F. of each of the cells was carefully compared with that of a Weston standard cell maintained at constant temperature, while its own temperature was carried several times over the entire range to which it had been subjected during the course of the outside work. It was found that the total variation in E. M. F. corresponding to the temperature range from +35° C. to —16°.5 C. was an increase of 1% for one cell and a decrease of 1.4% for the other. It is true that most of the variations in E. M. F. corresponded to the lower temperature, but it is interesting in this con-

nection to note that the temperature coefficients for the two cells were of *opposite* sign while the phenomena observed in the two earth-plate circuits were of *like* sign. The significant thing, however, is that, regardless of sign, the temperature effects in the potentiometer cells could account for only about 1% of the actual E. M. F. variations which were observed in the earth-plate circuits.

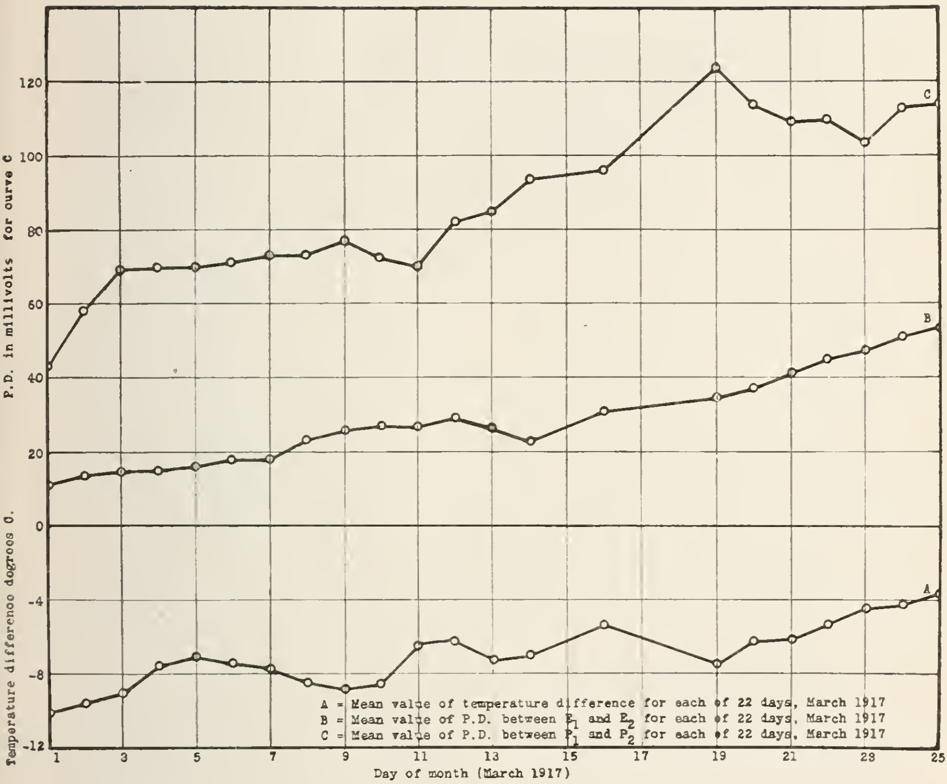

FIG. 5.

During the period between February 20 and March 1 the temperature at the upper electrodes was very unsteady, apparently passing several times through a critical value. After March 1, however, it never went below —1°.0, and advanced rapidly with the season. The curves of Fig. 5 represent the progressive change of the three elements from March 1 to March 25, 1917. It is obvious that the mean values for each day cannot show as well defined a parallelism between the curves as would be seen from the hourly

values for a single day, or, better still, the mean hourly values of several days. However, the general parallelism of the curves in Fig. 5 is in marked contrast to the opposed curvatures between the P. D. curves and the temperature-difference curve of Fig. 4. Not only was the sign of the temperature effect after March 1 again as it had been before January 25, but the relation between change of temperature difference and change of P. D. was again practically as before.

As a matter of fact, the lack of parallelism in Fig. 5 is due mainly to the effects of unequal moisture conditions in the two circuits. As previously stated, it was not possible to maintain identical conditions for the two circuits in this respect. In general, it was found that for equal changes in temperature difference the corresponding change in P. D. increased somewhat with the degree of moisture. For example, for two months before the beginning of the autumn rains, when the soil was very dry, the mean change in P. D. per degree change in temperature difference was about ten per cent lower than the mean of all days, while during winter and early spring it was about ten per cent above the mean. In addition to this effect of moisture on the relation between temperature difference and P. D., however, there were large effects directly resulting from moisture changes, which were observable even in the absence of variations in the temperature difference. It is this effect which was responsible for the difference between the average daily changes in P. D. for the two circuits during March.

Conclusions (Part 2).

1. The results given above, while strictly applicable only to the present installation, show the general nature and the order of magnitude of the effects to be expected when two earth-plates are subjected to a variable difference of temperature.

2. It appears that the natural plate E. M. F. between two electrodes buried at different depths in the same vertical may, on account of changes in their temperature difference, have a diurnal variation as large as that which has been ascribed by some observers to a true vertical earth-current. The diurnal variations observed by Brunhes (*l. c.*) at the Messeix mines certainly seem to be explainable on this basis.

3. Such effects as the observed prevailing tendency of earth-currents to flow from the foot of a mountain to its summit, and the

marked relation between the activity of a volcano and the direction of current flowing up or down its sides, must certainly be considerably influenced by the effects of temperature difference on the plate E. M. F., and may perhaps not be as completely controlled by atmospheric-electric phenomena as has sometimes been supposed.

4. It is evident that care should be taken to have earth-plates buried well below the frost level of the soil. This would apply with especial force to plates located on mountain summits, or where it is desired for special reasons to limit the depth.

5. Since the average diurnal variation for horizontal earth-currents as deduced from the results of measurements on lines not more than several kilometers in length is of the order of 0.001 volt/km. per hour, it is obvious that adequate provision should be made either for eliminating or taking account of temperature-difference effects. This would especially be the case with measurements made at different depths to determine the variation of earth-current density with depth.

6. It has long been recognized that non-polarizable electrodes are desirable for earth-current measurements. Such an electrode usually consists of a zinc or copper plate immersed in a solution of zinc sulphate or of copper sulphate, respectively, contained in a porous earthen vessel. When it is considered, however, that $Zn/ZnSO_4$ and $Cu/CuSO_4$ junctions have each a thermoelectric power of nearly a millivolt per degree, it would seem that the use of such electrodes is not, for short earth-current lines, a sufficient precaution for ensuring reliability of results, unless one can also be sure that temperature differences are negligible.

7. The importance of controlling spurious variations in earth-current measurements lies, of course, in the fact that most of the definite knowledge which we can hope to secure concerning earth-currents, must come from a study of their variations. This is especially true where the interrelations between earth-currents and terrestrial magnetism are concerned.

Department of Terrestrial Magnetism,
Carnegie Institution of Washington.

3. Magnetic Observatory at Kakioka, Japan.[1] This new observatory began its work in January 1913, taking the place of the former magnetic observatory which was in the grounds of the Central Meteorological Observatory in Tokio and which had been subject to the effects from electric car lines. The new observatory is in latitude 36° 13′ 51″ N, longitude 140° 11′ 21″ E, and its altitude above sea-level is 28.2 meters. The observatory compound comprises about 11,800 square meters and the natural features of the location afford reasonable assurance against future electric-car disturbances. The variometer-building is an underground structure with granite walls around it, the inner dimensions being 6.2 x 3.6 meters. The absolute building, built of wood, is 20 meters southeast of the variometer-house. The recording instruments are of the Eschenhagen pattern, made by Töpfer and Son. The absolute instruments are of the Wild design (unifilar magnetometer and earth inductor).

4. Prospective Magnetic Work on Amundsen Arctic Expedition. The Department of Terrestrial Magnetism of the Carnegie Institution of Washington, in accordance with a request from Captain *Roald Amundsen*, has supplied for use in his forthcoming arctic expedition a complete set of magnetic instruments, as also the necessary directions for magnetic measurements and the program of work. Captain Amundsen plans to leave Norway next summer, and has made arrangements on the expectation that his expedition will require about five years for completion. He will make scientific observations of various kinds in the arctic regions. During a visit to the laboratory of the Department at Washington by Dr. Nansen and Captain Amundsen on April 5, 1918, the final details as to the contemplated arctic magnetic observations were arranged.

5. Principal Magnetic Storms at Cheltenham Magnetic Observatory.[2]

Latitude 38° 44′.0 N; Longitude 76° 50′.5W, or $5^h\ 07^m$ 4W of Greenwich. January 1 to March 31, 1918.

Greenwich Mean Time		Range		
Beginning	Ending	Declination	Hor'l Intens.	Vert'l Intens.
h m	h	′	γ	γ
Feb. 11, 18 51	Feb. 13, 5—	32.9	115	126
Mar. 7, 21 12	Mar. 8, 9—	72.9	291	516

6. Personalia. We regret to record the death on January 20 of *Rollin A. Harris*, the well-known authority on the theory of tides, at the age of fifty-five years. *W. F. G. Swann* has been appointed professor of physics at the University of Minnesota, Minneapolis; he is succeeded in the Department of Terrestrial Magnetism by *S. J. Barnett*, of Columbus, Ohio. *L. A. Bauer* has been elected a foreign correspondent member of the Royal Society of Natural Sciences of Netherlands India.

[1] Extracted from *Ann. Rep. of Central Meteorological Observatory of Japan* (Magnetic observations in the year 1913), Tokyo, 1917.

[2] Communicated by *E. Lester Jones*, Superintendent Coast and Geodetic Survey; *Geo. Hartnell*, Observer-in-charge.

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Bauer, L. A. Annual report of the Director of the Department of Terrestrial Magnetism, Carnegie Institution of Washington, 1917. Repr. Washington, D. C., Carnegie Inst., Year Book, No. 16, 1917 (249-284, with 1 pl.). 25 cm. [Contains plate showing the magnetic-survey work of the Department of Terrestrial Magnetism during the period 1905-1917 (October).]

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Fig. 1.—Photograph by L. A. Bauer at Corona, Colorado, before Totality.
(Showing Solarized Crescent and Weather Conditions.)

Fig. 2.—Photograph by L. B. Aldrich at Lakin, Kansas.
(Reproduced with the permission of the Smithsonian Institution.)

Views of Solar Eclipse, June 8, 1918.

Terrestrial Magnetism
and
Atmospheric Electricity

VOLUME XXIII SEPTEMBER, 1918 NUMBER 3

RESULTS OF MAGNETIC AND ELECTRIC OBSERVATIONS MADE DURING THE SOLAR ECLIPSE OF JUNE 8, 1918.

BY L. A. BAUER, H. W. FISK, AND S. J. MAUCHLY.

1. The solar eclipse of June 8, 1918, since somewhat over one-third of the belt of totality was situated in the United States, offered an exceptional opportunity for astronomical and geophysical observations of various kinds. The Department of Terrestrial Magnetism of the Carnegie Institution of Washington confined its attention to magnetic, electric and allied observations. An appeal for cooperative work by institutions favorably situated, was published by L. A. Bauer in the March 1918 issue of this Journal, and the proposed program of work was communicated to interested persons, universities and observatories. As a result of this appeal, data have been obtained at a sufficient number of stations, both inside and outside the entire belt of totality. We desire to record here our appreciation of the effective cooperation received, as well as of the promptness with which the data have been forwarded to us.

2. It will be seen from Fig. 1 that the path, or belt, of totality passed about midway between the existing magnetic observatories, the positions of which are shown by the mark +. Thus Kakioka (Japan), Sitka (Alaska), Meanook and Agincourt (both in Canada), and Cheltenham (Maryland) were to the north of the belt; Apia (Samoa), Honolulu (Hawaii), and Tucson (Arizona) were to the south of the belt. Antipolo (Philippines) and Lukiapang (China) were just west of the beginning of the belt, while Vieques (Porto Rico) was just east of the end of it.

3. Another interesting circumstance about the present eclipse was the fact that it was the repetition of the one of May 28, 1900.

The belt of totality of the latter passed through the southeastern part of the United States during the morning hours, whereas that for the eclipse of June 8, 1918 passed through the United States from northwest to southeast during the *afternoon* hours. Thus, conditions were in a certain sense reversed for the two eclipses as far as the regular diurnal variation of the Earth's magnetism is concerned. It may be recalled that we began our first systematic observations for the study of a possible magnetic effect during a total solar eclipse with the eclipse of May 28, 1900.[1] (See Fig. 2.)

4. The following is the general scheme of work which was proposed; however, detailed directions and observation forms were also supplied to all who had signified their willingness to participate in the observations. The adoption of a definite program of observation and of an explicit observation-record assisted greatly in securing the desired uniformity and in simplifying the labor of reduction. The latter work, as far as was necessary, was performed at the Department of Terrestrial Magnetism by Messrs. L. A. Bauer, C. R. Duvall, H. M. W. Edmonds, H. B. Hedrick, H. W. Fisk, C. C. Ennis, S. J. Mauchly, W. J. Peters, and D. M. Wise.

General Scheme of Work.

1. Simultaneous magnetic observations of any or all of the elements according to the instruments at the oberver's disposal, every minute from June 8, 1918, 7 P. M. to 1 A. M. June 9, Greenwich civil mean time, or from June 8, 7^h to 13^h Greenwich astronomical mean time.

(To insure the highest degree of accuracy, the observer should begin work early enough to have everything in complete readiness in proper time. See precautions taken in previous eclipse work as described in the journal *Terrestrial Magnetism*, Vol. V., page 146, and Vol. VII., page 16. *Past experience has shown it to be essential that the same observer make the readings throughout the entire interval.*)

2. At magnetic observatories, all necessary precautions should be taken to insure that the self-recording instruments will be in good operation not only during the proposed interval but also for some time before and after, and eye-readings should be taken in addition wherever it is possible and convenient. (*It is recommended that, in general, the magnetograph be run on the usual speed throughout the interval, and that, if a change in recording speed be made, every precaution possible be taken to guard against instrumental changes likely to affect the continuity of the base line.*)

3. Atmospheric-electric observations should be made to the extent possible with the observer's equipment and personnel at his disposal.

4. Meteorological observations in accordance with the observer's equip-

[1]Bauer, L. A.: Résumé of magnetic observations made chiefly by the United States Coast and Geodetic Survey on the day of the total solar eclipse, May 28, 1900; *Terr. Mag.*, vol. 5, 1900, pp. 143-165.

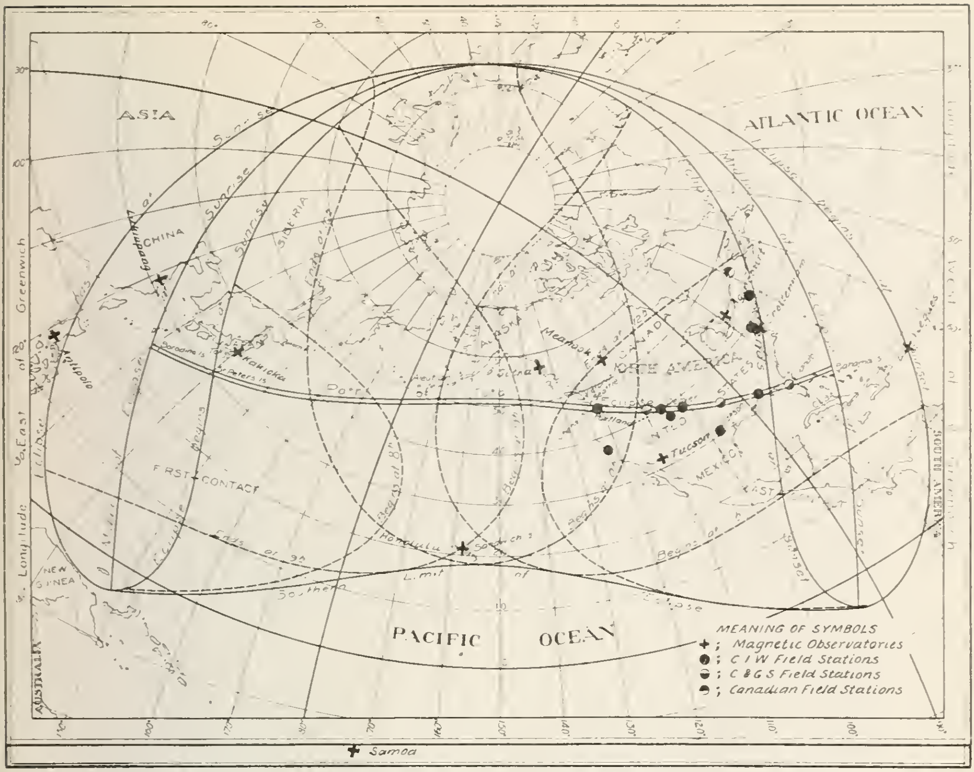

Fig. 1.—Map showing Region of Visibility of Solar Eclipse of June 8, 1918.

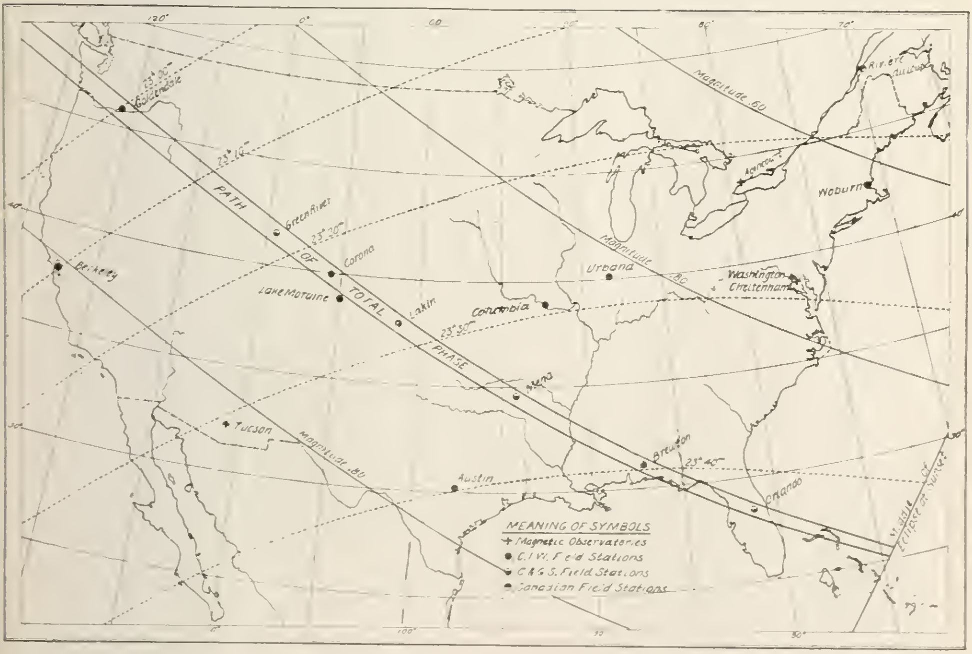

Fig. 2.—Path of Totality of Solar Eclipse, June 8, 1918, in the United States.

ment should be made at convenient periods (as short as possible) throughout the interval. It is suggested that, at least, temperature be read every fifth minute (directly after the magnetic reading for that minute).

5. Observers in the belt of totality are requested to take the magnetic reading every thirty seconds during the interval, 10 minutes before and 10 minutes after the time of totality, and to read temperature also every thirty seconds, between the magnetic readings.

5. In accordance with this scheme, cooperative observations were secured by the United States Coast and Geodetic Survey at their 5 observatories, and at 3 field stations in the belt of totality,[2] viz., Green River, Wyoming; Mena, Arkansas; and Orlando, Florida; by the Dominion Astronomical Observatory of Canada at a field station at Rivière du Loup, Quebec[3]; by the Canadian Meteorological Service at its 2 magnetic observatories, Agincourt and Meanook[4]; by Prof. W. J. Raymond of the University of California, at Berkeley; by Prof. J. M. Kuehne of the University of Texas, near Austin; by Prof. C. T. Knipp of the University of Illinois, at Urbana; by Prof. H. B. Wahlin of the University of Missouri, at Columbia; and by Prof. G. L. Hosmer of the Massachusetts Institute of Technology, at Woburn, a suburb of Boston. Professors Raymond, Kuehne, Knipp, Wahlin and Hosmer were associated with the Department of Terrestrial Magnetism, which furthermore assigned observers at 4 points along the path of totality, viz.: Goldendale, Washington; Corona, Colorado; Lakin, Kansas; and Brewton, Alabama. Observations were also made by the Department at Lake Moraine, Colorado, just south of the path of the eclipse, at the standardizing magnetic observatory at Washington, D. C., and at Watheroo, Australia. It is possible to include in the discussion also data from the magnetic observatories at Lukiapang (China), and Antipolo (Philippine Islands).[5]

Goldendale was the observing station for the astronomical observations of the Lick Observatory; Green River was the station of the Mt. Wilson Observatory and of the Yerkes Observatory; and Lakin was the station of the Smithsonian Institution. There were thus obtained both astronomical and geophysical data at 3 stations in the belt of totality.

6. The circumstances of the eclipse and details regarding the work at such stations will be given later, but for convenience all the

[2]See report by D. L. Hazard, this issue, pp. 111-120.

[3]See report by C. A. French, this issue, p. 121.

[4]See report by R. F. Stupart, this issue, pp. 121-125.

[5]See the respective reports by J. de Moidrey and M. Saderra Masó, pp. 126 and 137.

stations included in this report are given here, arranged in 3 groups as follows:

I Field Stations Within Belt of Totality	II Field Stations Outside Belt of Totality	III Observatory Stations
1. Goldendale, Wash.	8. Berkeley, Cal.	14. Lukiapang, China
2. Green River, Wyo.	9. Lake Moraine, Colo.	15. Antipolo, Philippine Is.
3. Corona, Colo.	9a. Urbana, Ill.	16. Kakioka, Japan
4. Lakin, Kansas	9b. Columbia, Mo.	17. Apia, Samoa
5. Mena, Arkansas	10. Austin, Texas	18. Honolulu, Hawaii
6. Brewton, Alabama	11. Washington, D. C.	19. Sitka, Alaska
7. Orlando, Florida	12. Woburn, Mass.	20. Meanook, Canada
	13. Rivière du Loup, Can.	21. Tucson, Arizona
		22. Agincourt, Canada
		23. Cheltenham, Maryland
		24. Vieques, Porto Rico
		25. Watheroo, Australia.

An endeavor was made to distribute the stations within the belt of totality in the United States with some degree of uniformity, from the Pacific to the Atlantic coast. (See Fig. 2.)

Stations and Observations of the Department of Terrestrial Magnetism

7. *Goldendale, Washington*, having been selected as observing station by the astronomical party of the Lick Observatory and by a party from the Weather Bureau, was chosen as the most western station. The observations were in charge of H. W. Fisk, who was assisted by C. C. Ennis of the Department and by G. W. Borden, county engineer, and M. H. Spalding, both of whom were employed for the occasion. An attempt was made here to observe changes in all three magnetic elements by the use of the ordinary field equipment. Three stations were therefore chosen in the city park where rapid temperature changes were reduced in some measure by the shade of a grove of large pine trees. For declination and inclination observations, the instruments were set up in the usual field tents. For the horizontal intensity a very convenient place was found in the "Blockhouse", a log structure built in pioneer days for defense purposes and more recently removed to the park for preservation. It has no windows other than very narrow slits, or port-holes, and the only door opens in the northwest end where the direct rays of the Sun cannot enter until late in the afternoon. As the blockhouse was well shaded by the pines, it was found that the temperature changes were very slow during the middle of the day. As a further protection, the instrument was packed in cotton in a specially constructed

housing of fiber board, so that uncertainties from this source were practically eliminated.

8. The instrument at Goldendale was the magnetometer portion of magnetometer-inductor No. 26, the inductor parts and the base being used at the inclination station. The deflecting magnet was placed at the shortest practical distance, and the whole instrument was firmly clamped to the top of a post set in the earth-floor of the blockhouse. Readings were then made every minute in the same manner as for declination. At the inclination station, an earth inductor of the magnetometer-inductor type designed for field use by the Department of Terrestrial Magnetism was employed. By making use of the micrometer, provided for setting the vertical circle, it was found possible to make readings at short intervals with sufficient accuracy to follow the diurnal changes quite closely, but, unfortunately, a mechanical difficulty developed from continued use of the instrument over so long a period, the exact nature of which was not recognized in time; hence, the inclination results were rendered of small value for the purpose intended. With some additional precautions and a slight modification of procedure, there is reason to believe that this type of field instrument can be successfully used to observe diurnal variation in inclination. The weather conditions on June 8 at Goldendale were favorable for good observations all day; the light cirrus clouds which gathered during the forenoon very fortunately parted at the moment of totality so that the eclipse was visible in a clear sky.

9. *Corona, Colorado,* a station of the Denver and Salt Lake railroad, the so-called "Moffat Road," was about 65 miles west of Denver, on the summit of the divide where the railroad crosses the Rocky Mountains; it was selected especially on account of the high altitude, about 11,800 feet. This was L. A. Bauer's station, who associated with him in the work Prof. E. Waite Elder and Mr. R. Sutton, both of the East End High School of Denver. Mr. Britt, the telegraph operator at Corona, also cooperated by making some astronomical observations with a newly purchased 3.5-inch refracting telescope. The weather conditions though unsatisfactory (hail, rain and clouds) during the first half of the time of the eclipse, were good throughout the greater part of totality. (See Pl. I, Fig. 1, and Fig. 4.)

10. *Lakin, Kansas,* the main station of the Department, was not

Fig. 3.—H. W. Fisk's Station at Goldendale, Washington.

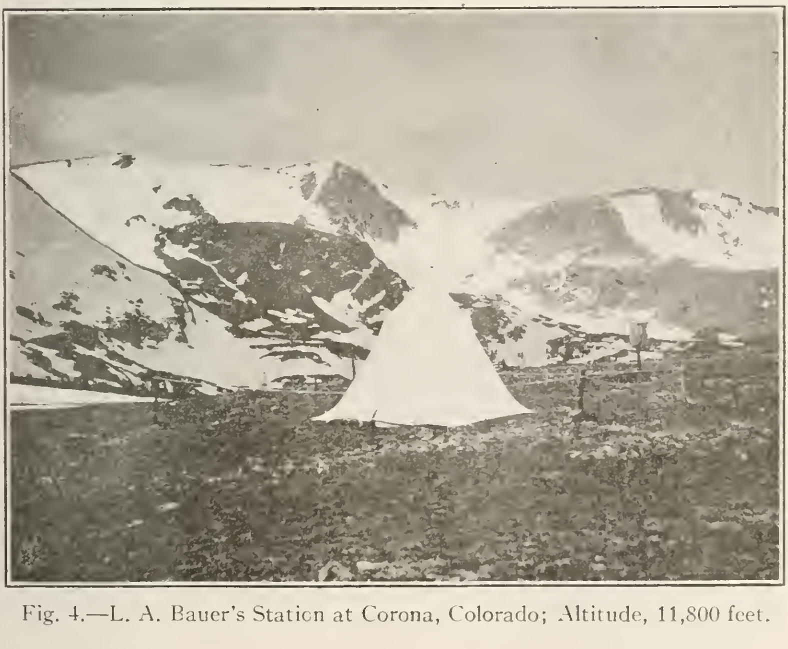

Fig. 4.—L. A. Bauer's Station at Corona, Colorado; Altitude, 11,800 feet.

meters from the nearest street traffic. The station is about 200 meters east a north-south, double-track electric car-line which maintains frequent but somewhat irregular service. About 1300 meters west of the station is a street on which are two electric lines, each of which operates trains of 2 or 3 to 7 or 8 cars every 20 minutes each way.

"The magnet used has a moment of about 560 units. It was suspended by a strip of phosphor-bronze rolled from a wire 0.0036 cm. in diameter and 38.5 cm. in length. . . . A twist of 180° in the suspending strip deflected the magnet less than 3′.6. . . . The suspended magnet was shielded from sunlight and from all disturbances, except magnetic ones. A small mirror attached to the magnet permitted its azimuth to be observed by means of a telescope and scale, set up in a fixed position, 261.5 cm. from the mirror. Angles were measured from an arbitrarily assumed meridian, and were estimated to 0′.1. . . .

"Means of the scale readings were computed for intervals of 5 minutes and reduced to angular measure. When these 5-minute mean results were plotted, a periodic variation became apparent, maxima occurring every 20 minutes, and at the same times on successive days. The amplitude of the variation was from 0′.2 to 0′.4 early in the afternoon, increasing to nearly 1′ toward 6 P. M. (Standard Time). Small magnetic disturbances had been expected from the street-car line about 200 meters distant, but it was not expected that the electric trains more than 1300 meters away would affect the needle sensibly. It was found, however, that not only was there coincidence between the time schedule of the trains and the observed periodicity of the curves, but the amplitude of the curves increased with the traffic toward 6 o'clock in the evening."

14. The variations referred to by Prof. Raymond, it may be noted, are in the 5-minute means. The variations in individual readings are of course much larger than the limits he names. In the Berkeley graph (Fig. 7, page 110) the irregular solid line shows these periodic fluctuations as they appear from the 5-minute means. The dotted line running through it is a smoothed curve derived by combining these means in groups of four, that is, all the readings within the 20-minute period, successively, taking numbers 1, 2, 3, and 4 for the first value, numbers 3, 4, 5, and 6 for the second, 5, 6, 7, and 8 for the third and so forth. The resulting curve shown in the dotted line has lost the periodic electric car effect, and with it doubtless some of the short-period details of the diurnal-variation curve, although it plainly shows the characteristic features of curves for the other stations.

15. At the time of the eclipse, W. J. Peters of the Department was at work in the mountains in the neighborhood of Pikes Peak, Colorado. He selected for his eclipse station, a point near *Lake Moraine, Colorado,* at an altitude of about 10,220 feet, where the eclipse was very nearly total, the magnitude being about 0.99. Clouds gathered in the early afternoon, and later about the time

of the eclipse there was a violent thunder storm with rain and hail.

16. The observations at *Austin, Texas,* were made by Prof. J. M. Kuehne of the University of Texas, using a theodolite-magnetometer built by Berger and Sons. His station was on the grounds of the Esperanza School, about 4 miles north of the State Capitol. There was a light shower during the earlier part of the observations followed by heavy cloudiness later in the afternoon. Prof. C. T. Knipp's observing station at *Urbana, Illinois,* was at the 1917 station of the Coast and Geodetic Survey; the sky was clear and there was no wind. The observations at *Columbia, Missouri,* by Prof. H. B. Wahlin, were made at the Coast and Geodetic Survey station of 1916. The weather conditions were: Cloudiness to begin with, 0.7 and at end, 0.1; moderately strong wind at beginning and none appreciable at end; humidity high.

17. At *Washington, D. C.,* declination observations were made in the standardizing magnetic observatory of the Department by C. R. Duvall.

18. At *Woburn,* a suburb of Boston, Massachusetts, the declination observations were made by Prof. G. L. Hosmer of the Massachusetts Institute of Technology, using an Elliott magnetometer No. 68, belonging to the Institute. His station was about 650 feet east of a north-south electric car-line. At both Washington and Woburn some electric-car effects in the form of small pulsations are noted, though much smaller than those recorded at Berkeley, and it is not probable that the form of the curve as plotted from the 5-minute means is appreciably altered because of their presence.

Geographic Positions and Circumstances of the Eclipse.

19. The geographic positions and local circumstances of the eclipse are given in Table 1. The positions are as observed or as reported by the observers; the eclipse circumstances were deduced from the predictions in the supplement to the American Ephemeris for 1918. The quantities under "Distance" are approximate distances in minutes of arc, north or south of the corresponding points on the center line of the eclipse. The column under "G. M. T." shows the approximate time of mid-totality. The other columns are self-explanatory. For convenient reference there are included in this table the 3 stations (Nos. 2, 5 and 7) at which observations were made by the observers of the United States Coast and Geodetic Survey.

Table 1.—*Stations in belt of totality (Group I).*

No.	Station	Latitude	Longitude	Distance	G.M.T.	Duration	Inst.	Chief of Party
		° ′	° ′	′	h m	s		
1	Goldendale	45 50 N	120 50W	1.5 N	23 00	117	CIW M13	H. W. Fisk
2	Green River	41 32 N	109 28W	1.5 S	18	99	CS M17	S. A. Deel
3	Corona	39 57 N	105 42W	2. N	23	92	CIW M14	L. A. Bauer
4	Lakin	37 53 N	101 18W	1.5 S	28	84	CIW M10	S. J. Mauchly
5	Mena	34 35 N	94 14W	2. N	35	70	CS M19	W. M. Merrymon
6	Brewton	31 07 N	87 04W	3. S	40	59	CIW M 4	C. W. Hewlett
7	Orlando	28 33 N	81 21W	7. N	42	48	CS M29	J. R. Benton

20. The geographic positions and eclipse circumstances of the field stations outside of the belt of totality, (Group II), are shown in Table 2. The Greenwich mean time and degree of maximum obscuration are given in the columns headed, respectively, "G. M. T." and "Mag." The Canadian station, Rivière du Loup, is likewise given in this table.

Table 2.—*Field stations outside belt of totality (Group II).*

No.	Station	Latitude	Longitude	G.M.T	Mag.	Inst.	Observer
		° ′	° ′	h m			
8	Berkeley	37 51 N	122 16W	23 10	0.79	Lab.	W. J. Raymond, Univ. of Cal.
9	Lake Moraine	38 49 N	105 00W	23 25	0.99	No. 16	W. J. Peters, C. I. W.
9a	Urbana	40 06 N	88 14W	23 28	0.83	Lab.	C. T. Knipp, Univ. of Ill.
9b	Columbia	38 56 N	92 20W	23 29	0.89	Lab.	H. B. Wahlin, Univ. of Mo.
10	Austin	30 20 N	97 24W	23 40	0.87	9710	J. M. Kuehne, Univ. of Texas
11	Washington	38 58 N	77 04W	23 29	0.74	No. 2	C. R. Duvall, C. I. W.
12	Woburn	42 30 N	71 06W	23 23	0.63	Kew 68	G. L. Hosmer, Mass. Inst. of Tech.
13	Rivière du Loup	47 52 N	69 34W	23 16	0.52	No. 20	C. A. French, Dom. Astron. Obs'y

21. Fig. 2 shows the distribution of the various stations in the United States and Canada at which magnetic data were obtained during the eclipse of June 8, 1918.

Magnetic-Declination Data.

22. The readings of the declination values were made by all the observers at the same instants as nearly as conditions would permit, care having been taken to obtain the correction of the timepiece used in each case on Greenwich mean time so that the readings were on the full minute. These readings were then combined in such a way that the means, in general, fall on the multiples of 5 minutes on and after the hour. As a consequence the five-minute means tabulated for the different stations of Group I are directly comparable (Table 3).

TABLE 3.—*Five-minute means of declination observations during the solar eclipse, June 8, 1918 (Group I).*[6]

Greenwich Mean Time	1. Goldendale Washington	3. Corona, Colorado	4. Lakin, Kansas	6. Brewton, Alabama	Greenwich Mean Time	1. Goldendale, Washington	3. Corona, Colorado	4. Lakin, Kansas	6. Brewton, Alabama
	E 23°+	E 15°+	E 12°+	E 4°+		E 23°+	E 15°+	E 12°+	E 4°+
h m	'	'	'	'	h m	'	'	'	'
19 01	19.0	42.0	25.4	15.7	22 00	16.2	41.5	25.7	19.0
05	18.5	41.7	25.1	15.5	05	16.4	41.6	25.8	19.3
10	17.8	41.7	25.0	15.5	10	16.6	42.2	26.0	19.3
15	17.7	41.4	24.9	15.5	15	16.9	42.5	26.2	19.5
20	17.2	41.2	24.7	15.4	20	16.9	42.9	26.3	19.6
25	17.1	41.1	24.5	15.3	25	17.2	43.3	26.5	19.7
30	16.7	40.9	24.4	15.4	30	17.1	43.4	26.8	19.7
35	16.5	40.7	24.3	15.5	35	17.4	43.6	27.1	19.8
40	16.4	40.6	24.3	15.6	40	17.4	43.7	27.3	20.0
45	16.2	40.4	24.3	15.6	45	17.2	44.3	27.4	20.1
50	16.2	40.3	24.4	15.9	50	17.4	44.3	27.6	20.1
55	16.3	40.5	24.6	16.1	55	17.4	44.2	27.6	20.1
20 00	16.2	40.3	24.9	16.2	23 00	17.3	44.4	28.0	20.1
05	16.5	40.2	25.0	16.4	05	17.2	44.5	28.3	20.2
10	16.6	40.5	25.2	16.7	10	17.3	44.7	28.7	20.4
15	16.7	40.4	25.1	16.8	15	17.3	44.8	28.8	20.4
20	16.5	39.8	25.0	16.8	20	17.5	45.0	29.0	20.4
25	16.1	39.5	24.9	16.9	25	17.7	45.0	29.3	20.5
30	15.6	39.4	24.7	16.9	30	17.4	45.0	29.2	20.5
35	15.6	39.9	24.6	16.8	35	17.5	45.3	29.4	20.7
40	15.6	41.0	24.4	16.8	40	17.5	45.9	29.6	20.6
45	15.6	41.4	24.4	16.8	45	17.4	45.8	29.7	20.7
50	15.7	41.4	24.5	17.0	50	17.7	46.0	29.9	20.8
55	15.8	41.6	24.5	17.1	55	18.1	46.5	30.0	20.7
21 00	16.4	41.9	24.8	17.3	24 00	18.1	46.6	30.0	21.0
05	16.8	42.6	25.3	17.8	05	18.2	46.6	30.3	21.1
10	16.8	42.9	25.5	18.2	10	18.6	46.7	30.6	21.1
15	16.6	43.0	25.7	18.3	15	18.7	47.1	30.6	21.1
20	16.6	42.8	25.7	18.4	20	18.6	47.1	30.6	21.2
25	16.2	42.1	25.7	18.4	25	18.2	47.2	30.8	21.2
30	16.1	42.1	25.7	18.5	30	18.2	47.2	31.0	21.2
35	16.0	41.8	25.8	18.6	35	18.3	47.3	31.1	21.1
40	16.2	41.9	25.8	18.8	40	18.3	47.2	31.2	21.0
45	15.8	41.5	25.8	18.8	45	18.3	46.9	30.8	20.7
50	15.9	41.2	25.8	18.9	50	18.1	46.6	30.7	20.4
55	15.8	41.2	25.6	19.0	55	17.9	46.3	30.6	20.4
					59	17.8	46.4	30.5	20.4

[6] For the data at the Coast and Geodetic Survey stations, see this issue, pp. 111-120.

23. The readings at the stations outside the belt of totality, Group II, were made in the same manner as for Group I, except that there was no period of half-minute readings to correspond with the readings during totality at the stations within the belt. The five-minute means were formed as for Group I; Table 4 gives these mean values.

TABLE 4.—*Five-minute means of declination observations during the solar eclipse, June 8, 1918 (Group II)*[7].

Greenwich Mean Time	8. Berkeley, California	9. Lake Moraine, Colorado	10. Austin, Texas.	11. Washington, D. C.	12. Woburn, Massachusetts	13. Revière du Loup, Canada	Greenwich Mean Time	8. Berkeley, California	9. Lake Moraine, Colorado	10. Austin, Texas	11. Washington, D. C.	12. Woburn, Massachusetts	13. Revière du Loup, Canada
	East 18°10′+	East 14°+	East 9°+	West 4°+	West 13°+	West 21°+		East 18°10′+	East 14°+	East 9°+	West 4°+	West 13°+	West 21°+
h m	′	′	′	′	′	′	h m	′	′	′	′	′	′
19 01	5.1	55.0	05.8	47.3	42.2	34.1	22 00	2.9	55.4	06.4	41.5	34.1	24.8
05	4.5	54.8	05.4	47.4	42.0	34.2	05	2.8	55.6	06.5	41.6	34.0	24.4
10	4.3	54.6	04.8	47.4	41.8	34.0	10	3.5	56.0	06.7	41.6	33.6	24.5
15	4.7	54.4	04.7	47.4	41.4	33.2	15	3.9	56.3	06.7	41.3	33.3	24.6
20	3.7	54.2	04.9	47.5	41.5	33.1	20	4.9	56.6	06.8	41.5	33.6	24.9
25	3.4	54.1	05.0	47.3	41.8	32.8	25	4.4	56.9	07.0	41.4	34.0	25.6
30	3.1	54.0	04.8	47.3	41.3	32.8	30	4.5	57.0	07.1	41.3	33.6	25.7
35	3.3	53.8	04.8	47.2	41.4	32.6	35	5.5	57.2	07.2	41.4	33.7	25.8
40	3.2	53.8	04.8	46.9	40.8	32.5	40	6.1	57.3	07.4	41.3	33.3	25.8
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50	3.2	53.9	04.8	46.2	39.8	30.4	50	5.2	57.6	07.6	41.1	33.3	26.3
55	4.0	54.2	04.8	45.6	39.0	29.1	55	5.7	57.9	07.7	41.2	33.5	26.2
20 00	3.4	54.4	04.8	45.1	38.6	28.8	23 00	5.7	58.1	07.8	41.1	33.3	26.2
05	3.6	54.7	04.8	44.7	38.1	27.6	05	5.1	58.2	08.0	41.1	33.3	26.2
10	3.3	54.9	04.9	44.1	37.1	26.5	10	5.6	58.4	08.2	40.8	33.0	26.2
15	3.4	55.0	04.9	44.0	36.7	26.2	15	5.7	58.7	08.4	40.8	32.5	26.1
20	3.0	55.0	05.2	43.9	36.7	26.7	20	6.0	58.8	08.5	41.0	32.5	25.7
25	1.9	54.8	05.1	43.9	36.8	27.2	25	5.3	59.0	08.6	40.4	32.4	25.5
30	2.0	54.7	05.1	44.1	37.0	28.3	30	5.6	59.0	08.8	40.5	32.1	25.6
35	2.4	54.6	05.0	44.0	37.1	28.0	35	5.6	59.0	08.8	40.3	31.7	25.2
40	3.8	54.4	04.9	43.8	36.5	27.4	40	5.6	59.0	08.9	40.2	31.7	25.1
45	2.4	54.4	04.9	43.8	36.2	26.7	45	6.1	59.3	09.2	40.1	31.7	25.4
50	2.4	54.7	05.0	43.4	36.0	26.2	50	5.6	59.5	09.4	39.9	32.0	25.8
55	2.8	54.6	05.2	43.2	35.6	25.4	55	5.5	59.8	09.5	40.1	32.3	26.5
21 00	3.4	55.1	05.4	42.8	35.0	24.1	24 00	6.1	59.8	09.6	39.9	32.1	25.8
05	3.1	55.4	05.7	42.2	34.3	22.7	05	5.2	60.0	09.8	39.8	32.3	25.1
10	2.7	55.6	06.0	41.7	33.5	21.9	10	5.9	60.2	09.8	39.6	31.8	25.4
15	3.7	55.9	06.1	41.9	33.6	23.3	15	6.8	60.5	10.0	39.8	31.6	25.6
20	3.4	55.8	06.1	42.0	34.0	24.3	20	6.8	60.6	10.1	39.6	31.8	25.7
25	2.0	55.6	06.2	42.1	34.6	24.6	25	6.1	60.6	10.2	39.6	31.9	25.6
30	2.9	55.6	06.3	41.9	34.2	24.5	30	6.3	60.7	10.2	39.7	31.4	25.6
35	2.6	55.6	06.4	41.8	33.9	24.4	35	6.4	60.7	10.1	39.6	31.5	25.9
40	3.0	55.7	06.4	42.0	34.0	24.5	40	6.4	60.6	10.1	39.6	31.8	25.8
45	2.3	55.5	06.4	41.9	34.0	24.8	45	6.4	60.6	10.1	40.0	31.6	26.5
50	3.4	55.6	06.4	41.7	34.3	25.3	50	6.4	60.4	09.9	40.3	32.4	26.9
55	3.5	55.4	06.3	42.0	34.2	25.4	55	6.6	60.2	09.7	40.3	32.4	26.8
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(*To be continued.*)

Table 4.—*Five-minute means of declination observations during the solar eclipse, June 8, 1918 (Group II* [7].

Greenwich Mean Time	8. Berkeley, California	9. Lake Moraine, Colorado	10. Austin, Texas.	11. Washington, D. C.	12. Woburn, Massachusetts	13. Revière du Loup, Canada	Greenwich Mean Time	8. Berkeley, California	9. Lake Moraine, Colorado	10. Austin, Texas	11. Washington, D. C.	12. Woburn, Massachusetts	13. Revière du Loup, Canada
	East 18°10′+	East 14°+	East 9°+	West 4°+	West 13°+	West 21°+		East 18°10′+	East 14°+	East 9°+	West 4°+	West 13°+	West 21°+
h m	′	′	′	′	′	′	h m	′	′	′	′	′	′
19 01	5.1	55.0	05.8	47.3	42.2	34.1	22 00	2.9	55.4	06.4	41.5	34.1	24.8
05	4.5	54.8	05.4	47.4	42.0	34.2	05	2.8	55.6	06.5	41.6	34.0	24.4
10	4.3	54.6	04.8	47.4	41.8	34.0	10	3.5	56.0	06.7	41.6	33.6	24.5
15	4.7	54.4	04.7	47.4	41.4	33.2	15	3.9	56.3	06.7	41.3	33.3	24.6
20	3.7	54.2	04.9	47.5	41.5	33.1	20	4.9	56.6	06.8	41.5	33.6	24.9
25	3.4	54.1	05.0	47.3	41.8	32.8	25	4.4	56.9	07.0	41.4	34.0	25.6
30	3.1	54.0	04.8	47.3	41.3	32.8	30	4.5	57.0	07.1	41.3	33.6	25.7
35	3.3	53.8	04.8	47.2	41.4	32.6	35	5.5	57.2	07.2	41.4	33.7	25.8
40	3.2	53.8	04.8	46.9	40.8	32.5	40	6.1	57.3	07.4	41.3	33.3	25.8
45	3.2	53.7	04.8	46.4	40.2	31.5	45	5.1	57.5	07.4	41.4	33.3	26.2
50	3.2	53.9	04.8	46.2	39.8	30.4	50	5.2	57.6	07.6	41.1	33.3	26.3
55	4.0	54.2	04.8	45.6	39.0	29.1	55	5.7	57.9	07.7	41.2	33.5	26.2
20 00	3.4	54.4	04.8	45.1	38.6	28.8	23 00	5.7	58.1	07.8	41.1	33.3	26.2
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10	3.3	54.9	04.9	44.1	37.1	26.5	10	5.6	58.4	08.2	40.8	33.0	26.2
15	3.4	55.0	04.9	44.0	36.7	26.2	15	5.7	58.7	08.4	40.8	32.5	26.1
20	3.0	55.0	05.2	43.9	36.7	26.7	20	6.0	58.8	08.5	41.0	32.5	25.7
25	1.9	54.8	05.1	43.9	36.8	27.2	25	5.3	59.0	08.6	40.4	32.4	25.5
30	2.0	54.7	05.1	44.1	37.0	28.3	30	5.6	59.0	08.8	40.5	32.1	25.6
35	2.4	54.6	05.0	44.0	37.1	28.0	35	5.6	59.0	08.8	40.3	31.7	25.2
40	3.8	54.4	04.9	43.8	36.5	27.4	40	5.6	59.0	08.9	40.2	31.7	25.1
45	2.4	54.4	04.9	43.8	36.2	26.7	45	6.1	59.3	09.2	40.1	31.7	25.4
50	2.4	54.7	05.0	43.4	36.0	26.2	50	5.6	59.5	09.4	39.9	32.0	25.8
55	2.8	54.6	05.2	43.2	35.6	25.4	55	5.5	59.8	09.5	40.1	32.3	26.5
21 00	3.4	55.1	05.4	42.8	35.0	24.1	24 00	6.1	59.8	09.6	39.9	32.1	25.8
05	3.1	55.4	05.7	42.2	34.3	22.7	05	5.2	60.0	09.8	39.8	32.3	25.1
10	2.7	55.6	06.0	41.7	33.5	21.9	10	5.9	60.2	09.8	39.6	31.8	25.4
15	3.7	55.9	06.1	41.9	33.6	23.3	15	6.8	60.5	10.0	39.8	31.6	25.6
20	3.4	55.8	06.1	42.0	34.0	24.3	20	6.8	60.6	10.1	39.6	31.8	25.7
25	2.0	55.6	06.2	42.1	34.6	24.6	25	6.1	60.6	10.2	39.6	31.9	25.6
30	2.9	55.6	06.3	41.9	34.2	24.5	30	6.3	60.7	10.2	39.7	31.4	25.6
35	2.6	55.6	06.4	41.8	33.9	24.4	35	6.4	60.7	10.1	39.6	31.5	25.9
40	3.0	55.7	06.4	42.0	34.0	24.5	40	6.4	60.6	10.1	39.6	31.8	25.8
45	2.3	55.5	06.4	41.9	34.0	24.8	45	6.4	60.6	10.1	40.0	31.6	26.5
50	3.4	55.6	06.4	41.7	34.3	25.3	50	6.4	60.4	09.9	40.3	32.4	26.9
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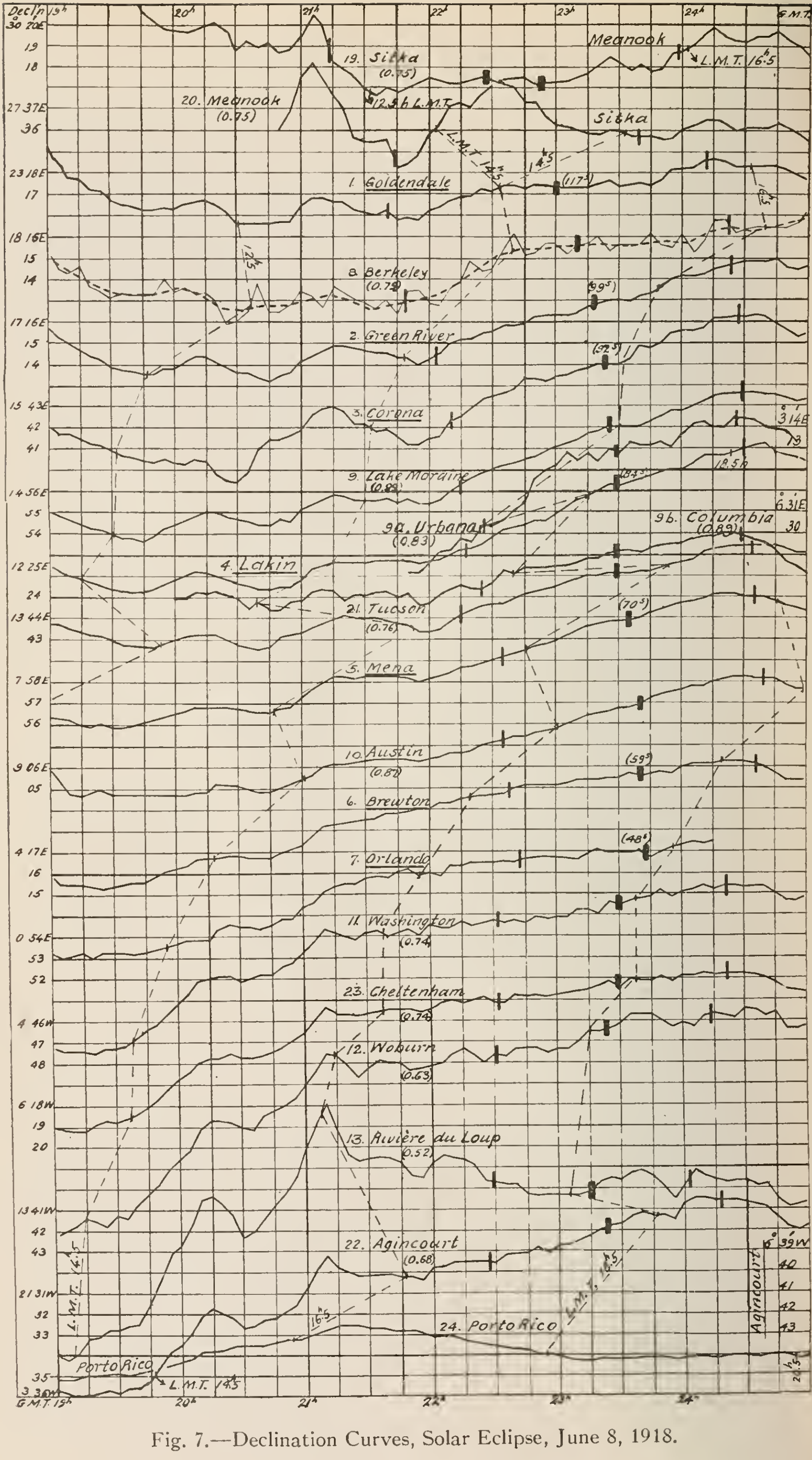


Fig. 7.—Declination Curves, Solar Eclipse, June 8, 1918.

RESULTS OF MAGNETIC OBSERVATIONS MADE BY THE UNITED STATES COAST AND GEODETIC SURVEY AT THE TIME OF THE SOLAR ECLIPSE OF JUNE 8, 1918.

By D. L. Hazard, *Chief of Division of Terrestrial Magnetism.*

In response to the request[1] of Dr. L. A. Bauer, director of the Department of Terrestrial Magnetism of the Carnegie Institution of Washington, for additional data for the study of the effect of an eclipse of the Sun upon the Earth's magnetism, the Coast and Geodetic Survey arranged to have special observations made at 3 field stations in the belt of totality. Eye readings of declination were made every minute for six hours beginning at 7 P. M., Greenwich mean time (Table 4). For a period of 20 minutes about the time of totality, eye readings were made every 30 seconds. Temperature readings were made every 5 minutes (Table 5). In addition, the usual observations of declination, dip and horizontal intensity were made for secular change data, these being stations at which observations had been made before. Table 1 gives the location of the 3 field stations.

Table 1.—*Location of 3 field stations.*

Place	State	Latitude	Longitude	Magnetometer	Observer
		° ′	° ′		
Orlando	Florida	28 33 N	81 21 W	No. 29	J. R. Benton
Mena	Arkansas	34 35 N	94 14 W	No. 19	Wm. W. Merrymon
Green River	Wyoming	41 32 N	109 28 W	No. 17	S. A. Deel

The magnetometers used are of the Coast Survey pattern, one division of the scale of the collimator magnet being equal to 2′.0.

At *Orlando* it was overcast and showery for most of the period and about three quarters of an hour before the time for closing the eye readings the rain became so severe that it was deemed best to bring the observations to a close.

At *Mena* the weather was showery at the beginning of the period, but at the time of the beginning of the eclipse it had cleared and continued clear until the end of the observations. At this station special eye readings were also made on June 7 at five- or ten-minute intervals for the same six-hour period as on June 8.

[1]See *Terr. Mag.*, vol. 23, p. 32, 1918.

At *Green River* it was cloudy at intervals during the period of observations but cleared just after the second contact and remained so until the close of the observations. Eye readings were also made at five-minute intervals on June 10, but as this was a day of considerable magnetic disturbance, the observatons were of little value for this investigation.

In addition to the observations at the 3 field stations in the belt of totality, eye-readings of declination were made for the same period at each of the 5 magnetic observatories of the Coast and Geodetic Survey (Table 7). At Cheltenham these observations were made with the declination variometer of the Adie magnetograph, as the magnetometer is not provided with a scale for eye readings. At the other observatories a magnetometer of the India Survey pattern was used, the value of one division of the scale being approximately 1′.4.

Care was taken to have the variation instruments in good working order on the day of the eclipse. All of the observatories are supplied with a magnetograph of the Eschenhagen type with a time scale of 20 mm. to the hour. The change of temperature in the instrument room during the 6 hours in no case amounted to more than 0°.1 centigrade.

The values of declination, horizontal intensity, and vertical intensity have been derived from the magnetograms for every 5 minutes of the period (Tables 8, 9, 10). In reading the ordinates from the magnetograms, a graphical integration was made so that a tabular result is approximately the average value for the five-minute period of which the tabular time is in the middle.

The location of the observatories, Greenwich astronomical mean time and magnitude of maximum obscuration, and data regarding the variometers are given in Tables 2 and 3 (see also Table 11.)

Table 2.—*Location of the 5 magnetic observatories.*

Observatory	State	Latitude	Longitude	Maximum Obscuration		Observer-in Charge
				G.M.T	Mag.	
		° ′	° ′	h m		
Vieques	Porto Rico	18 08.8 N	65 26.9 W	....	......	W. M. Hill
Cheltenham	Maryland	38 44.0 N	76 50.5 W	11 29	0.74	G. Hartnell
Tucson	Arizona	32 14.8 N	110 50.1 W	11 30	0.76	H. E. McComb
Sitka	Alaska	57 03.0 N	135 20.1 W	10 27	0.75	F. P. Ulrich
Honolulu	Hawaii	21 19.2 N	158 03.8 W	9 45	0.09	F. Neumann

TABLE 3.—*Magnetic elements and scale values for June, 1918.* (*See Table 11.*)

Observatory	Approximate Magnetic Elements			Scale Values of the Magnetograph		
	D	H	Z	D	H	Z
	° ′	γ	γ	′	γ	γ
Porto Rico	3 34 W	27995	34780	1.02	2.37	6.58
Cheltenham	6 12 W	19230	55465	1.00	2.55	4.30
Tucson	13 47 E	26980	45710	1.00	2.44	2.25
Sitka	30 21 E	15590	55830	1.02	4.16	6.07
Honolulu	9 48 E	28910	23780	1.02	2.78	3.46

TABLE 4.—*Five-minute means of declination observations at the 3 field stations on June 8, 1918.*

G.M.T.	Orlando (East)	Mena (East)	Green River (East)	G.M.T.	Orlando (East)	Mena (East)	Green River (East)
h m	° ′	° ′	° ′	h m	° ′	° ′	° ′
19 00	0 53.17	7 56.36	17 15.66	22 00	0 56.99	7 58.14	17 14.12
05	52.97	56.30	15.24	05	56.91	58.28	14.48
10	53.03	56.22	14.96	10	57.31	58.46	14.92
15	53.17	55.96	14.70	15	57.31	58.66	15.06
20	52.99	55.88	14.38	20	57.43	58.74	15.12
25	53.23	56.00	14.16	25	57.47	58.92	15.42
30	53.25	55.86	13.86	30	57.49	59.02	15.54
35	53.17	55.88	13.80	35	57.53	59.14	15.80
40	53.13	55.94	13.80	40	57.51	59.36	15.80
45	53.23	56.04	13.62	45	57.61	59.54	15.88
50	53.47	56.20	13.60	50	57.75	59.76	16.14
55	53.55	56.40	13.88	55	57.81	59.82	16.20
20 00	53.65	56.52	13.88	23 00	57.73	59.92	16.18
05	53.89	56.64	14.10	05	57.75	60.18	16.24
10	53.91	56.82	14.30	10	57.69	60.40	16.36
15	53.91	56.86	14.32	15	57.93	60.58	16.72
20	54.36	56.82	14.10	20	58.05	60.72	16.84
25	54.58	56.86	13.90	25	57.97	60.82	16.96
30	54.46	56.80	13.68	30	57.95	60.86	16.98
35	54.48	56.66	13.66	35	57.97	60.88	16.92
40	54.36	56.60	13.36	40	58.01	60.98	17.12
45	54.52	56.62	13.18	45	57.73	61.20	17.28
50	54.72	56.78	13.46	50	57.97	61.42	17.60
55	54.92	56.86	13.66	55	58.17	61.56	18.00
21 00	55.36	57.22	14.10	24 00	58.33	61.66	18.10
05	55.56	57.66	14.42	05	58.45	61.82	18.06
10	56.08	57.98	14.64	10	58.41	61.92	18.18
15	56.36	58.22	14.90	15	58.43	62.02	18.52
20	56.51	58.22	14.88	20	....	62.10	18.64
25	56.49	58.16	14.78	25	....	62.06	18.74
30	56.75	58.22	14.70	30	....	61.98	18.90
35	56.83	58.26	14.62	35	....	62.00	18.90
40	56.81	58.28	14.56	40	....	61.94	18.88
45	57.03	58.24	14.28	45	....	61.80	18.96
50	57.15	58.20	14.26	50	....	61.58	18.54
55	56.91	58.00	13.98	55	....	61.48	18.46
				25 00	....	61.38	18.64

Table 5.—*Temperatures (centigrade) at the 3 field stations during period of observations, at time of solar eclipse June 8, 1918.*

G.M.T.	Orlando	Mena	Green River	G. M. T.	Orlando	Mena	Green River
h m	°	°	°	h m	°	°	°
19 00	29.4	20.8	31.3	22 00	27.0	23.1	34.2
05	27.2	21.3	32.8	05	27.0	23.2	32.0
10	26.6	21.2	35.3	10	27.0	23.3	28.2
15	25.8	21.2	31.8	15	26.9	23.6	27.8
20	25.0	21.7	31.6	20	26.5	23.8	34.5
25	25.6	21.3	31.3	25	25.8	23.8	31.8
30	25.2	21.3	32.5	30	25.6	24.1	32.6
35	25.0	21.2	32.0	35	25.8	24.2	32.6
40	25.2	21.3	33.0	40	25.8	24.2	29.8
45	27.0	21.5	32.3	45	26.8	23.9	28.5
50	28.1	21.7	33.5	50	28.0	23.2	27.4
55	29.2	21.5	34.8	55	26.8	23.4	26.8
20 00	29.3	21.4	33.2	23 00	25.4	23.1	27.0
05	31.0	21.5	34.4	05	25.6	23.1	28.1
10	30.6	21.7	34.9	10	25.7	23.0	27.9
15	30.0	21.8	35.0	15	25.1	22.8	27.8
20	28.9	21.8	36.6	20	25.0	22.7	25.9
25	29.3	22.1	33.2	25	25.0	22.8	25.2
30	29.0	21.8	33.0	30	25.0	22.5	25.2
35	29.0	21.8	33.8	35	25.0	22.3	25.7
40	28.0	21.8	34.0	40	25.0	22.4	25.8
45	28.0	21.7	34.2	45	25.0	22.6	26.0
50	27.5	21.8	35.5	50	25.1	22.7	26.5
55	26.7	22.0	34.2	55	25.1	22.5	26.9
21 00	27.0	....	32.1	24 00	25.0	22.1	27.0
05	27.0	21.6	33.2	05	25.0	22.0	27.3
10	27.1	22.0	34.1	10	25.0	21.9	27.5
15	27.7	21.8	36.0	15	25.2	21.8	28.0
20	27.2	21.9	37.3	20	....	21.8	28.3
25	27.0	21.9	34.4	25	....	21.9	28.0
30	27.0	22.0	35.3	30	....	21.8	27.1
35	27.0	22.2	34.4	35	....	21.7	27 8
40	27.1	22.3	28.8	40	....	21.7	27.9
45	27.2	22.7	35.4	45	....	21.8	27.6
50	27.0	22.9	33.5	50	....	21.8	27.5
55	27.0	23.0	33.8	55	....	21.7	27.4
				25 00	....	21.6	26.7

Table 6.—*Results of declination observations at Mena, Arkansas, on June 7, 1918.*

G. M. T.	Declination (East)	G. M. T.	Declination (East)	G. M. T.	Declination (East)
h m	° ′	h m	° ′	h m	° ′
19 00	7 56.4	21 00	7 57.0	23.00	8 00.4
10	56.8	10	57.1	10	00.7
15	56.8	15	57.3	15	00.8
20	56.9	20	57.5	20	01.1
30	57.1	30	57.7	30	01.5
40	57.3	40	57.7	40	01.4
45	57.1	45	57.8	45	01.6
50	57.1	50	58.1	50	01.8
20 00	57.1	22 00	58.3	24 00	02.2
10	57.0	10	58.8	10	02.4
15	56.9	15	58.9	15	02.2
20	56.8	20	58.9	20	02.0
30	57.0	30	59.4	30	01.6
40	56.9	40	59.7	40	01.5
45	57.0	45	59.9	45	01.4
50	56.9	50	60.1	50	01.4
				25 00	01.0

TABLE 7.—*Five-minute means of declination from eye-readings on June 8, 1918.*

G.M.T.	Porto Rico	Cheltenham	Tucson	Sitka	Honolulu
h m	° ′	° ′	° ′	° ′	° ′
19 00	3 35.2W	6 19.0W	13 43.7 E	30 26.9 E	9 51.1 E
05	35.2	19.1	43.7	26.3	51.1
10	35.1	19.2	43.5	25.7	51.1
15	35.0	19.2	43.3	25.5	51.1
20	35.0	18.9	43.2	24.4	50.9
25	35.0	18.7	43.1	23.7	50.8
30	34.9	18.8	43.0	23.1	50.7
35	35.0	18.6	42.8	21.9	50.4
40	34.9	18.4	42.8	21.1	50.0
45	34.7	18.1	42.8	20.5	49.9
50	34.6	17.7	42.7	19.7	49.8
55	34.5	17.1	42.9	19.5	49.8
20 00	34.3	16.7	43.0	19.4	49.8
05	34.2	16.3	43.1	19.3	49.8
10	33.9	15.9	43.2	19.5	49.7
15	33.8	15.7	43.2	19.8	49.7
20	33.8	15.7	43.2	20.0	49.7
25	33.6	15.5	43.0	19.2	49.6
30	33.5	15.7	42.8	18.7	49.5
35	33.6	15.7	42.7	19.3	49.3
40	33.6	15.6	42.6	19.0	49.0
45	33.4	15.4	42.7	18.7	48.7
50	33.3	15.2	43.1	18.4	48.6
55	33.3	14.9	43.2	18.7	48.5
21 00	33.2	14.5	43.3	19.2	48.5
05	33.0	13.9	43.6	20.2	48.6
10	32.8	13.3	43.8	19.5	48.4
15	32.7	13.6	44.0	18.2	48.3
20	32.7	13.6	44.1	17.6	48.2
25	32.7	13.7	44.0	17.1	48.1
30	32.8	13.6	44.0	16.6	48.0
35	32.8	13.5	44.0	16.5	47.6
40	32.9	13.4	43.9	16.9	47.4
45	32.9	13.4	43.8	16.7	47.2
50	32.9	13.4	43.7	16.7	47.1
55	33.0	13.5	43.4	17.2	47.0
22 00	33.1	13.4	43.4	17.1	46.9
05	33.1	13.1	43.5	16.9	46.9
10	33.1	13.0	43.8	16.7	46.9
15	33.3	13.1	44.1	16.7	46.9
20	33.5	13.0	44.4	17.0	46.9
25	33.6	12.9	44.6	16.9	46.9
30	33.7	13.1	44.7	17.0	46.9
35	33.7	13.1	44.7	16.6	46.9
40	33.8	12.8	44.9	16.3	46.9
45	33.9	12.9	45.1	15.8	46.8
50	34.0	12.8	45.2	15.2	46.8
55	34.0	12.9	45.4	14.8	46.8
23 00	34.1	12.8	45.5	14.5	46.9
05	34.2	12.7	45.7	14.2	46.9
10	34.2	12.6	45.9	14.1	46.9
15	34.2	12.5	46.0	14.1	46.9
20	34.1	12.3	46.0	14.1	46.9
25	34.2	12.1	46.1	14.2	46.9
30	34.2	12.4	46.1	13.9	46.9
35	34.2	12.0	46.1	13.7	46.9
40	34.1	12.1	46.2	13.5	46.9
45	34.1	12.1	46.2	13.4	46.9
50	34.1	11.9	46.4	13.4	47.0
55	34.2	12.1	46.6	13.7	47.0
24 00	34.1	11.9	46.7	14.1	47.1
05	34.0	11.9	46.8	14.2	47.2
10	34.1	11.8	47.1	14.7	47.4
15	34.1	11.9	47.2	14.6	47.6
20	34.0	11.8	47.3	14.1	47.7
25	34.0	11.8	47.4	13.8	48.0
30	34.0	11.8	47.4	13.8	48.0
35	34.1	11.9	47.4	14.0	48.0
40	34.0	12.0	47.4	14.0	48.1
45	34.0	12.2	47.4	14.3	48.2
50	34.1	12.5	47.3	14.1	48.2
55	34.2	12.6	47.1	13.4	48.2
25 00	34.1	12.7	47.1	13.4	48.2

TABLE 8.—*Magnetograph values of declination on June 8, 1918.*

G.M.T.	Porto Rico	Cheltenham	Tucson	Sitka	Honolulu
h m	° ′	° ′	° ′	° ′	° ′
19 00	3 35.8W	6 19.0W	13 44.0 E	30 26.7 E	9 51.2 E
05	35.7	19.1	43.9	26.3	51.2
10	35.7	19.2	43.8	25.8	51.1
15	35.7	19.2	43.5	25.5	50.9
20	35.6	19.0	43.3	24.9	50.9
25	35.6	18.9	43.2	24.1	50.8
30	35.6	18.8	43.1	23.2	50.6
35	35.5	18.8	43.0	22.2	50.4
40	35.4	18.6	43.0	21.6	50.2
45	35.3	18.3	43.0	20.7	50.2
50	35.2	17.8	43.0	20.3	50.1
55	35.0	17.2	43.0	19.9	50.1
20 00	34.8	16.8	43.0	19.8	50.0
05	34.7	16.3	43.0	19.7	50.0
10	34.6	15.8	43.0	19.8	49.9
15	34.5	15.7	43.1	20.0	49.8
20	34.4	15.6	43.1	20.1	49.6
25	34.2	15.5	43.0	19.8	49.4
30	34.1	15.6	43.0	18.9	49.2
35	34.1	15.6	43.0	19.3	49.2
40	34.1	15.5	42.9	19.0	49.1
45	34.1	15.5	42.9	19.1	49.0
50	34.0	15.2	43.0	18.7	48.9
55	33.9	14.8	43.2	18.9	48.8
21 00	33.8	14.5	43.5	19.5	48.8
05	33.5	13.8	43.8	20.5	48.5
10	33.4	13.2	43.9	19.9	48.4
15	33.3	13.5	44.0	18.2	48.2
20	33.3	13.4	44.0	17.9	48.1
25	33.4	13.5	44.0	17.5	48.0
30	33.4	13.4	44.0	16.9	47.9
35	33.4	13.2	44.0	16.7	47.7
40	33.4	13.2	44.0	17.0	47.5
45	33.5	13.2	44.0	16.9	47.3
50	33.5	13.3	44.0	17.0	47.2
55	33.6	13.3	43.8	17.3	47.1
22 00	33.7	13.2	43.8	17.5	47.0
05	33.7	13.1	43.9	17.4	47.0
10	33.8	12.9	43.9	17.3	46.9
15	33.9	12.8	44.1	17.3	46.9
20	33.9	12.8	44.5	17.4	46.9
25	34.0	12.7	44.7	17.5	46.8
30	34.1	12.8	44.9	17.4	46.8
35	34.1	12.8	45.0	17.2	46.8
40	34.2	12.7	45.1	17.0	46.8
45	34.3	12.6	45.2	16.3	46.8
50	34.4	12.6	45.4	16.0	46.8
55	34.5	12.5	45.6	15.6	46.8
23 00	34.6	12.5	45.7	15.2	46.9
05	34.7	12.3	45.8	15.1	46.9
10	34.7	12.3	46.0	15.0	46.9
15	34.7	12.2	46.0	14.9	46.8
20	34.7	12.2	46.1	14.9	46.9
25	34.7	12.1	46.1	15.0	46.9
30	34.7	12.0	46.2	15.0	46.9
35	34.7	11.9	46.3	14.7	46.9
40	34.6	11.7	46.4	14.7	47.0
45	34.6	11.7	46.5	14.7	47.0
50	34.6	11.6	46.6	14.6	47.1
55	34.7	11.7	46.9	14.7	47.2
24 00	34.6	11.5	46.9	15.1	47.2
05	34.5	11.5	47.0	15.3	47.3
10	34.5	11.5	47.1	15.5	47.6
15	34.5	11.5	47.2	15.5	47.9
20	34.4	11.5	47.3	15.3	47.9
25	34.4	11.5	47.4	15.0	48.0
30	34.4	11.5	47.5	15.1	48.0
35	34.4	11.5	47.5	15.1	48.0
40	34.4	11.6	47.5	15.1	48.1
45	34.5	11.8	47.4	15.3	48.1
50	34.6	11.9	47.3	15.1	48.1
55	34.6	12.2	47.2	14.8	48.1
25 00	34.6	12.4	47.1	14.5	48.1

TABLE 9.—*Magnetograph values of horizontal intensity on June 8, 1918.*

G.M.T.	Porto Rico	Cheltenham	Tucson	Sitka	Honolulu
h m	γ	γ	γ	γ	γ
19 00	28017	19268	27005	15589	28932
05	017	269	005	588	932
10	017	271	005	587	932
15	017	274	005	587	932
20	016	272	004	588	932
25	015	273	004	586	933
30	014	272	004	585	932
35	012	272	002	582	932
40	011	269	26999	581	932
45	009	268	998	576	932
50	009	267	996	573	932
55	008	267	996	571	932
20 00	007	266	995	569	932
05	006	266	994	567	932
10	005	266	994	566	932
15	005	268	995	570	932
20	004	268	996	577	931
25	004	267	998	584	931
30	004	269	27001	593	931
35	005	273	003	592	931
40	005	273	003	592	931
45	005	272	003	590	930
50	004	268	001	586	929
55	005	270	003	582	929
21 00	003	265	000	575	927
05	003	266	000	579	927
10	001	263	26999	585	925
15	000	259	998	586	924
20	000	257	998	589	924
25	000	256	999	593	924
30	000	253	998	593	924
35	27999	253	998	593	924
40	28000	254	998	594	924
45	000	253	999	601	924
50	001	253	27001	602	926
55	003	258	003	603	928
22 00	003	258	002	600	928
05	002	256	000	598	927
10	002	253	26998	596	927
15	002	251	997	595	927
20	002	249	996	596	927
25	002	248	996	597	927
30	003	249	996	599	927
35	003	249	996	600	928
40	004	249	996	602	928
45	005	248	995	604	928
50	005	247	994	603	927
55	004	244	992	601	927
23 00	004	243	991	598	927
05	005	242	989	596	927
10	004	240	988	594	927
15	005	240	987	593	927
20	005	240	987	593	927
25	005	240	987	593	927
30	006	240	988	594	928
35	007	244	988	597	928
40	007	242	987	598	927
45	006	241	986	596	927
50	005	238	984	594	925
55	003	234	981	591	924
24 00	003	234	981	591	923
05	002	236	981	590	922
10	002	236	980	590	922
15	002	234	980	591	922
20	002	235	981	593	922
25	002	237	982	597	922
30	002	237	983	600	923
35	002	237	983	599	923
40	002	238	984	599	924
45	002	237	984	596	924
50	002	238	985	596	924
55	002	240	985	597	924
25 00	003	242	986	599	926

TABLE 10.—*Magnetograph values of vertical intensity on June 8, 1918.*

G.M.T.	Porto Rico	Cheltenham	Tucson	Sitka	Honolulu
h m	γ	γ	γ	γ	γ
19 00	34789	55449	45700	55805	23789
05	790	449	701	804	788
10	790	450	702	804	788
15	791	450	702	804	788
20	791	451	702	805	786
25	791	451	702	805	785
30	791	452	702	806	785
35	790	453	702	807	784
40	790	454	702	807	784
45	790	455	702	807	784
50	790	455	702	807	784
55	790	455	702	807	784
20 00	790	456	702	807	784
05	789	456	702	807	784
10	788	456	702	807	784
15	788	457	702	807	784
20	788	457	702	807	783
25	788	458	702	808	782
30	788	458	702	811	781
35	788	458	703	809	781
40	789	459	703	809	781
45	790	460	704	809	781
50	788	460	704	810	780
55	788	460	704	810	780
21 00	788	461	705	807	778
05	785	463	705	807	778
10	784	464	705	806	778
15	783	464	705	810	777
20	783	464	705	811	777
25	783	464	706	811	775
30	783	464	706	811	775
35	783	463	706	811	774
40	783	464	707	811	774
45	783	464	707	811	774
50	783	464	708	810	774
55	784	465	709	810	774
22 00	785	465	709	810	774
05	784	466	709	810	774
10	784	466	709	810	774
15	784	466	709	811	774
20	783	466	710	811	775
25	783	466	710	812	775
30	784	465	710	812	776
35	784	465	711	813	777
40	785	465	711	814	777
45	785	464	711	815	777
50	785	464	711	815	777
55	784	462	711	814	777
23 00	784	462	711	813	777
05	784	462	711	812	778
10	784	461	711	812	778
15	784	461	711	812	778
20	784	460	712	812	778
25	784	460	712	812	779
30	784	460	712	812	780
35	784	460	712	813	780
40	784	459	713	813	780
45	784	460	713	813	780
50	783	460	713	813	780
55	783	458	713	813	780
24 00	783	458	713	813	781
05	783	459	714	814	781
10	782	459	714	814	781
15	782	458	715	814	781
20	781	458	715	815	781
25	781	458	716	816	781
30	781	458	716	818	781
35	781	458	716	818	781
40	780	458	716	818	781
45	780	457	716	818	781
50	781	457	716	817	781
55	781	457	716	818	781
25 00	781	457	716	818	781

The following tables (Nos. 12-14) show the diurnal variation of the magnetic elements at the magnetic observatories of the Coast and Geodetic Survey for June 1918, based on 10 selected quiet days (June 1, 2, 3, 4, 23, 24, 25, 28, 29, 30). Though June 8, the day of the solar eclipse, was not included in the 10 quiet days, the diurnal variation agrees very closely with the mean of the 10 days.

It should be noted that inasmuch as our monthly tabulations of hourly values are now based on the average ordinate for hourly periods beginning at midnight of the standard meridian time which falls nearest to the meridian of the observatory, the tabular values refer approximately to the middle of these hourly periods, that is, the first value in the table applies to zero hours and thirty minutes, the second value to one hour and thirty minutes and so on.

The + sign signifies eastward deflection of north end of needle, increasing horizontal or increasing vertical intensity.

TABLE 11.—*Mean values of the magnetic elements for June, 1918 (10 quiet days).*

	Porto Rico	Cheltenham	Tucson	Sitka	Honolulu
Declination	3°33′.6W	6°11′.7W	13°46′.7E	30°21′.2E	9°48′.6E
Horizontal Intensity	28005γ	19236γ	26995γ	15602γ	28920γ
Vertical Intensity	34776γ	55460γ	45708γ	55840γ	23784γ

TABLE 12.—*Diurnal variation of declination, June, 1918.*

Hour (m.t.)	Porto Rico	Cheltenham	Tucson	Sitka	Honolulu
Stand. Mer.	60°	75°	105°	135°	165°
h—h	′	′	′	′	′
0–1	−0.7	0.0	0.0	−1.1	−0.3
1–2	−0.4	+0.3	−0.1	−0.7	−0.1
2–3	−0.3	+0.4	+0.2	−0.4	+0.1
3–4	−0.2	+0.8	+0.4	+0.4	+0.5
4–5	+0.2	+1.6	+1.0	+2.3	+1.0
5–6	+0.7	+3.5	+1.8	+4.8	+2.3
6–7	+2.0	+5.9	+3.7	+6.6	+3.6
7–8	+3.4	+7.2	+4.9	+7.9	+3.8
8–9	+3.5	+6.0	+4.6	+7.6	+2.4
9–10	+2.5	+3.6	+2.9	+6.7	+0.6
10–11	+1.4	−0.4	+0.2	+3.2	−0.9
11–12	+0.5	−3.9	−2.1	−0.2	−1.8
12–13	−0.5	−5.4	−3.4	−2.6	−2.0
13–14	−1.2	−5.3	−3.6	−4.2	−1.9
14–15	−1.5	−4.7	−3.1	−5.8	−1.6
15–16	−1.7	−3.2	−2.5	−5.9	−1.1
16–17	−1.2	−1.9	−1.4	−5.0	−0.8
17–18	−0.8	−0.8	−0.6	−3.5	−0.6
18–19	−0.9	−0.2	−0.4	−2.3	−0.5
19–20	−1.0	−0.5	−0.6	−1.6	−0.5
20–21	−1.1	−1.0	−0.7	−1.6	−0.5
21–22	−1.2	−0.8	−0.6	−1.4	−0.6
22–23	−0.9	−0.9	−0.5	−1.6	−0.5
23–24	−0.8	−0.3	−0.4	−1.7	−0.4

TABLE 13.—*Diurnal variation of horizontal intensity, June, 1918.*

Hour (m.t.)	Porto Rico	Cheltenham	Tucson	Sitka	Honolulu
Stand. Mer.	60°	75°	105°	135°	165°
h h	γ	γ	γ	γ	γ
0–1	−5	+1	−1	+7	−9
1–2	−5	0	0	+7	−8
2–3	−5	+1	+2	+10	−6
3–4	−4	0	+2	+13	−6
4–5	−4	0	+3	+17	−6
5–6	−3	+1	+6	+18	−3
6–7	0	+1	+8	+17	+2
7–8	+2	−5	+4	+12	+5
8–9	+5	−14	−2	+5	+8
9–10	+9	−21	−1	−5	+10
10–11	+13	−18	+2	−17	+11
11–12	+12	−9	+3	−24	+12
12–13	+8	−1	+4	−22	+13
13–14	+5	+6	+4	−18	+11
14–15	+1	+12	+1	−15	+10
15–16	−1	+13	−2	−9	+6
16–17	−5	+12	−6	−6	0
17–18	−6	+7	−9	−1	−4
18–19	−5	+2	−7	+2	−7
19–20	−3	+2	−4	+1	−8
20–21	−3	+2	−2	0	−8
21–22	−2	+3	−3	+2	−8
22–23	−2	+3	−2	+3	−7
23–24	−2	+1	−1	+4	−7

TABLE 14.—*Diurnal variation of vertical intensity, June, 1918.*

Hour (m.t.)	Porto Rico	Cheltenham	Tucson	Sitka	Honolulu
Stand. Mer.	60°	75°	105°	135°	165°
h h	γ	γ	γ	γ	γ
0–1	−2	+1	+4	+2	+2
1–2	−2	0	+4	−1	+3
2–3	−3	0	+5	0	+4
3–4	−2	+1	+5	+4	+5
4–5	−3	+4	+6	+5	+6
5–6	−2	+4	+8	+4	+12
6–7	−3	+3	+10	+1	+14
7–8	−7	+2	+7	−4	+7
8–9	−6	0	+1	−9	−2
9–10	−2	−5	−7	−10	−8
10–11	+2	−8	−14	−12	−9
11–12	+2	−10	−16	−11	−8
12–13	+2	−9	−13	−9	−5
13–14	0	−5	−10	−4	−4
14–15	+2	−1	−6	−1	−3
15–16	+4	+3	−2	+6	−3
16–17	+4	+5	+1	+7	−3
17–18	+2	+5	+4	+9	−2
18–19	+2	+4	+4	+9	−2
19–20	+2	+3	+2	+6	−2
20–21	+2	+2	+2	+2	−1
21–22	+4	+1	+2	+2	−1
22–23	+2	+1	+2	+1	+1
23–24	+1	0	+2	+3	+2

MAGNETIC OBSERVATIONS MADE AT RIVIÈRE DU LOUP, CANADA, DURING THE SOLAR ECLIPSE OF JUNE 8, 1918.

By C. A. French.

I am sending[1] herewith the results of the special magnetic declination observations taken on June 8 in behalf of the Department of Terrestrial Magnetism of the Carnegie Institution of Washington, as well as additional observations taken at the eclipse station. Only part of the observations taken at the eclipse station are included, for the reason that during a greater part of the week, June 10-15, magnetic conditions were very disturbed. . . . As June 13 was the least disturbed of any day during the week, I am sending the dip observations taken on that day. The observations of declination, also the afternoon observations of horizontal intensity of June 13 are also included.

[Mr. French used universal magnetometer No. 20, of the C. I. W. pattern, the constants of which were determined by the Department of Terrestrial Magnetism. The observations were reduced and put in form for publication by Mr. C. C. Ennis of the Department of Terrestrial Magnetism; the values are given in Table 4, page 108.—Ed.]

[1]The observations were sent by Mr. French to his chief, Dr. Otto Klotz, director of the Ottawa Observatory, who kindly forwarded them to the Journal.—Ed.

RESULTS OF MAGNETIC OBSERVATIONS DURING THE SOLAR ECLIPSE OF JUNE 8, 1918, AT AGINCOURT AND MEANOOK, CANADA.

By R. F. Stupart, *Director of Meteorological Service, Canada.*

I have pleasure in furnishing herewith tables of magnetic values of declination, horizontal and vertical intensity for the Agincourt Magnetic Observatory and of declination for the Meanook Magnetic Observatory, these values being the results of our magnetic observations made in connection with the solar eclipse of June 8, 1918. The values furnished in each case for Agincourt and Meanook are from eye readings at minute intervals reduced to I. M. S.: at Agincourt, eye readings of differential magnetometers, and at Meanook, eye readings of magnetometer 48. The observer at Meanook was late starting owing to his having accidentally broken suspension in Elliott Magnetometer 48 on the morning of June 8.

[Tables 1-8 are based upon the data transmitted to the Journal. The data are plotted and discussed in the report by L. A. Bauer, H. W. Fisk and S. J. Mauchly, begun in this issue.—Ed.]

TABLE 1.—*Absolute values of declination (D) at Agincourt taken at minute intervals on June 8, 1918 from 19*^{h}*, June 8 to 1*^{h}*, June 9, G. M. T.*
[$D = 6°30'W +$ tabular value.]

Hour Minute	19^h	20^h	21^h	22^h	23^h	24^h	Hour Minute	19^h	20^h	21^h	22^h	23^h	24^h
m	′	′	′	′	′	′	m	′	′	′	′	′	′
0	15.7	13.5	10.9	9.8	8.6	6.5	30	16.0	12.8	10.1	9.5	7.9	6.7
1	15.6	13.3	10.8	9.9	8.7	6.6	31	15.9	12.6	10.2	9.6	7.7	6.7
2	16.0	13.7	10.3	9.6	8.7	6.6	32	15.9	12.6	10.1	9.4	7.5	6.6
3	15.8	13.2	10.4	9.6	8.8	6.6	33	15.8	12.6	10.1	9.2	7.4	6.7
4	16.1	13.1	10.1	9.8	8.6	6.5	34	15.8	12.6	10.1	9.2	7.3	6.8
5	16.0	12.9	9.8	9.6	8.6	6.4	35	15.4	12.6	10.1	9.1	7.3	7.1
6	15.8	12.8	9.6	9.9	8.6	6.4	36	15.6	12.6	10.0	9.1	7.2	6.7
7	16.1	12.6	9.2	9.8	8.8	6.6	37	15.7	12.4	10.1	9.1	7.3	6.9
8	16.2	12.4	8.9	9.9	8.7	6.6	38	15.7	12.4	10.1	9.1	7.3	6.9
9	16.0	12.3	8.9	9.5	8.7	6.4	39	15.6	12.3	10.0	9.1	7.1	6.9
10	16.0	12.1	9.2	9.4	8.4	6.4	40	15.8	12.0	10.1	9.1	7.0	6.9
11	16.0	11.7	9.7	9.5	8.3	6.5	41	15.6	12.3	10.0	9.1	7.0	6.9
12	16.0	11.8	9.5	9.7	8.5	6.5	42	15.4	12.2	10.1	9.2	7.3	7.3
13	15.8	11.7	9.8	9.7	8.5	6.6	43	15.3	12.2	10.2	9.0	7.3	7.3
14	16.1	11.7	9.8	9.6	8.4	6.6	44	15.3	12.1	10.2	9.2	7.4	7.3
15	16.0	11.7	9.9	9.4	8.2	6.6	45	15.3	12.2	10.2	9.2	7.3	7.4
16	16.0	11.7	9.9	9.4	8.1	6.5	46	15.2	12.1	10.3	9.0	7.3	7.6
17	16.0	11.8	9.8	9.8	8.1	6.6	47	15.1	12.2	10.3	9.0	7.3	7.8
18	15.8	11.9	9.8	9.8	8.2	6.5	48	15.0	12.1	10.2	9.0	7.4	7.8
19	16.0	11.9	9.9	9.6	8.1	6.6	49	14.9	11.9	10.3	8.8	6.9	7.8
20	16.0	12.0	10.0	9.4	8.0	6.5	50	14.6	12.0	10.3	8.9	7.0	7.8
21	15.9	11.9	10.1	9.4	7.8	6.6	51	14.2	11.9	10.1	8.9	7.3	8.2
22	15.8	12.0	10.1	9.5	7.9	6.5	52	14.0	11.8	10.3	9.0	7.4	8.1
23	15.8	12.1	10.2	9.6	8.0	6.6	53	13.9	11.9	10.6	9.2	7.5	7.8
24	15.5	12.1	10.2	9.5	7.9	6.4	54	14.0	11.6	10.5	9.2	7.6	8.0
25	15.5	12.2	10.2	9.6	7.7	6.6	55	13.8	11.5	10.4	9.1	7.5	8.0
26	15.6	12.1	10.2	9.4	7.6	6.6	56	13.8	11.4	10.3	9.0	7.4	8.3
27	16.1	12.4	10.2	9.5	7.8	6.5	57	13.8	11.4	10.1	8.9	7.4	8.1
28	16.0	12.7	10.1	9.6	7.7	6.5	58	13.8	11.2	10.1	8.9	7.0	7.9
29	15.8	12.7	10.2	9.7	7.8	6.6	59	13.4	11.0	9.9	8.9	6.9	7.8
30	16.0	12.8	10.1	9.5	7.9	6.7	60	13.5	10.9	9.8	8.6	6.5	8.0

TABLE 2.—*Five-minute means of declination (D) at Agincourt on June 8, 1918 from 19*^{h}*, June 8 to 1*^{h}*, June 9, G. M. T.*
[$D = 6°30'W +$ tabular value.]

Hour Minute	19^h	20^h	21^h	22^h	23^h	24^h	Hour Minute	19^h	20^h	21^h	22^h	23^h	24^h
m	′	′	′	′	′	′	m	′	′	′	′	′	′
0	.....	13.54	10.84	9.86	8.76	6.72	30	15.92	12.68	10.14	9.56	7.72	6.62
1	15.77[1]	.....	.....	.....	.....	....	35	15.66	12.56	10.08	9.14	7.30	6.84
5	15.96	12.92	9.82	9.74	8.68	6.50	40	15.62	12.24	10.06	9.12	7.14	6.98
10	16.04	12.06	9.24	9.60	8.52	6.48	45	15.24	12.16	10.24	9.08	7.32	7.48
15	15.98	11.72	9.84	9.58	8.26	6.58	50	14.54	11.94	10.24	8.92	7.20	7.94
20	15.90	11.94	9.98	9.54	8.00	6.54	55	13.86	11.56	10.38	9.08	7.48	8.04
25	15.70	12.18	10.20	9.52	7.80	6.54	59	.....	.....	.....	.....	.....	7.90[1]

[1]Three-minute mean.

TABLE 3.—*Absolute values of horizontal intensity (H) at Agincourt taken at minute intervals on June 8, 1918 from 19*ʰ*, June 8 to 1*ʰ*, June 9, G. M. T.*
[$H = 15900\gamma$ + tabular value.]

Hour Minute	19^h	20^h	21^h	22^h	23^h	24^h	Hour Minute	19^h	20^h	21^h	22^h	23^h	24^h
m	γ	γ	γ	γ	γ	γ	m	γ	γ	γ	γ	γ	γ
0	56	56	62	62	44	37	30	62	63	54	52	41	38
1	56	57	63	64	43	37	31	63	65	54	52	43	37
2	56	56	64	64	43	37	32	62	67	54	53	46	38
3	56	56	65	62	43	38	33	62	68	55	53	46	38
4	56	56	65	60	42	38	34	61	68	55	52	47	39
5	56	56	67	60	42	37	35	60	70	53	52	46	38
6	57	56	69	58	42	36	36	60	69	52	52	46	38
7	57	56	70	57	40	36	37	60	70	51	53	46	38
8	57	57	72	58	41	35	38	59	70	54	51	45	38
9	58	57	69	58	40	36	39	59	71	55	51	46	39
10	57	57	64	57	40	38	40	57	70	55	52	46	40
11	57	58	60	55	39	36	41	57	71	55	51	45	39
12	57	59	60	55	39	37	42	56	70	56	50	43	37
13	60	61	59	55	39	35	43	56	71	56	51	42	37
14	60	60	60	55	39	35	44	56	70	56	51	43	36
15	62	61	59	55	39	35	45	57	68	55	51	42	36
16	61	60	59	55	39	35	46	58	67	55	50	42	35
17	61	60	59	55	39	35	47	56	65	55	49	42	35
18	61	63	59	54	39	36	48	56	65	55	50	42	35
19	59	63	58	54	40	36	49	56	65	55	50	42	36
20	59	62	56	55	39	36	50	56	62	56	48	40	37
21	60	63	57	55	41	38	51	57	65	57	48	38	36
22	59	63	57	55	39	38	52	58	64	57	46	36	37
23	61	63	57	54	40	37	53	57	63	58	45	35	38
24	61	62	57	53	41	37	54	57	67	61	45	34	38
25	62	62	56	52	41	37	55	58	67	62	44	35	38
26	61	62	55	52	40	37	56	57	67	63	43	33	37
27	60	60	55	52	40	37	57	57	67	63	43	34	40
28	61	62	55	52	41	38	58	56	63	63	43	35	40
29	62	62	54	52	41	38	59	57	62	62	44	35	41
30	62	63	54	52	41	38	60	56	62	62	44	37	40

TABLE 4.—*Five-minute means of horizontal intensity (H) at Agincourt on June 8, 1918 from 19*ʰ*, June 8 to 1*ʰ*, June 9, G. M. T.*
[$H = 15900\gamma$ + tabular value.]

Hour Minute	19^h	20^h	21^h	22^h	23^h	24^h	Hour Minute	19^h	20^h	21^h	22^h	23^h	24^h
m	γ	γ	γ	γ	γ	γ	m	γ	γ	γ	γ	γ	γ
0	.....	56.4	62.8	63.0	43.4	36.2	30	62.0	63.8	54.2	52.2	42.4	37.8
1	56.0[1]	....	....	....	....	....	35	60.6	69.0	53.2	52.4	46.2	38.2
5	56.4	56.0	67.2	59.4	41.8	37.0	40	57.6	70.4	55.0	51.0	45.0	38.6
10	57.2	57.6	65.0	56.6	39.8	36.4	45	56.6	68.2	55.4	50.4	42.2	35.8
15	60.8	60.4	59.2	55.0	39.0	35.0	50	56.6	64.2	56.0	48.4	39.6	36.2
20	59.6	62.8	57.4	54.6	39.6	36.8	55	57.2	66.2	61.4	44.0	34.2	38.2
25	61.0	61.8	56.0	52.6	40.4	37.0	59	....	....	....	....	....	40.3[1]

[1]Three-minute mean.

Table 5.—*Absolute values of vertical intensity (Z) at Agincourt taken at minute intervals on June 8, 1918 from 19^h, June 8 to 1^h, June 9, G. M. T.*
[$Z = 58300\gamma +$ tabular value.]

Hour Minute	19^h	20^h	21^h	22^h	23^h	24^h	Hour Minute	19^h	20^h	21^h	22^h	23^h	24^h
m	γ	γ	γ	γ	γ	γ	m	γ	γ	γ	γ	γ	γ
0	61	65	67	74	72	72	30	64	67	70	74	74	72
1	60	65	68	75	72	72	31	63	67	70	74	74	73
2	60	65	68	75	72	72	32	63	67	70	74	74	72
3	61	65	69	75	72	72	33	63	68	69	74	75	72
4	61	65	69	75	72	72	34	63	67	70	73	74	71
5	61	66	70	74	72	72	35	63	68	71	73	74	72
6	61	65	71	74	72	72	36	63	67	70	73	74	73
7	62	64	71	74	72	72	37	63	67	71	73	74	73
8	62	65	71	75	72	71	38	63	67	71	74	74	72
9	62	65	70	75	73	72	39	63	67	71	74	74	73
10	62	65	70	75	72	71	40	64	67	72	73	74	73
11	62	65	69	75	72	72	41	63	66	72	73	74	72
12	63	66	69	74	73	72	42	63	67	72	73	74	72
13	63	66	69	74	72	72	43	63	67	72	72	73	71
14	63	66	69	75	72	72	44	63	67	72	72	73	72
15	63	66	69	74	72	72	45	64	67	72	73	73	72
16	63	66	69	75	72	71	46	64	67	73	73	72	73
17	63	66	69	75	72	71	47	64	66	72	74	72	72
18	63	66	69	74	72	71	48	63	67	72	73	73	72
19	63	67	69	74	73	72	49	63	67	72	72	73	72
20	63	66	69	74	74	71	50	63	66	72	73	72	72
21	63	66	69	74	72	71	51	63	66	73	72	71	72
22	63	66	69	74	74	71	52	63	66	73	72	71	72
23	63	66	70	74	73	72	53	63	66	74	72	71	71
24	64	67	69	74	73	72	54	63	67	73	73	71	72
25	63	67	69	74	73	72	55	63	67	75	73	71	72
26	63	66	70	73	73	72	56	64	67	75	72	70	73
27	63	65	70	73	75	72	57	64	67	74	73	71	73
28	63	66	69	74	73	73	58	65	67	75	72	72	73
29	63	66	70	74	73	72	59	64	67	75	72	71	72
30	64	67	70	74	74	72	60	65	67	74	72	72	72

Table 6.—*Five-minute means of vertical intensity (Z) at Agincourt on June 8, 1918 from 19^h, June 8 to 1^h, June 9, G. M. T.*
[$Z = 58300\gamma +$ tabular value.]

Hour Minute	19^h	20^h	21^h	22^h	23^h	24^h	Hour Minute	19^h	20^h	21^h	22^h	23^h	24^h
m	γ	γ	γ	γ	γ	γ	m	γ	γ	γ	γ	γ	γ
0	....	64.8	67.4	74.8	72.0	71.8	30	63.2	66.6	69.8	74.0	73.6	72.4
1	60.3[1]	....	....	....	....	....	35	63.0	67.4	70.2	73.2	74.2	72.2
5	61.2	65.0	70.0	74.4	72.0	72.0	40	63.2	66.8	71.6	73.4	74.0	72.4
10	62.2	65.2	69.8	74.8	72.4	71.6	45	63.6	66.8	72.2	72.8	72.6	72.0
15	63.0	66.0	69.0	74.6	72.0	71.6	50	63.0	66.4	72.4	72.4	72.0	72.0
20	63.0	66.2	69.0	74.0	73.0	71.2	55	63.4	66.8	74.2	72.6	70.8	72.2
25	63.2	66.2	69.6	73.6	73.4	72.0	59	....	....	....	....	....	72.3[1]

[1]Three-minute mean.

TABLE 7.—*Absolute values of declination (D) at Meanook taken at minute intervals on June 8, 1918 from 20^h 47^m, June 8 to 2^h 05^m, June 9, G. M. T.*
[$D=27°30'$E+tabular value.]

Hour Minute	20^h	21^h	22^h	23^h	24^h	25^h	26^h	Hour Minute	20^h	21^h	22^h	23^h	24^h	25^h
m	'	'	'	'	'	'	'	m	'	'	'	'	'	'
0	....	8.5	5.6	8.3	9.7	9.6	10.5	30	....	5.5	8.2	8.8	10.2	10.3
1	....	9.2	5.8	8.2	9.6	9.6	10.6	31	....	5.3	8.3	8.9	10.1	10.3
2	....	9.0	6.2	8.3	9.7	9.6	10.7	32	....	5.6	8.3	8.9	10.2	10.3
3	....	8.9	6.2	8.4	9.8	9.8	10.9	33	....	5.5	8.2	9.0	10.3	10.4
4	....	9.2	6.0	8.1	10.0	10.0	11.0	34	....	5.8	8.2	8.8	10.4	10.5
5	....	9.2	6.1	8.2	10.1	9.7	11.2	35	....	5.6	8.4	8.6	10.4	10.5
6	....	9.2	6.2	8.3	10.2	9.6	....	36	....	5.2	8.5	8.6	10.3	10.5
7	....	9.1	6.6	8.4	10.3	9.6	....	37	....	5.0	8.5	8.7	10.4	10.6
8	....	9.4	6.7	8.4	10.4	9.4	....	38	....	6.0	8.5	8.8	10.5	10.7
9	....	8.5	7.2	8.4	10.5	9.2	....	39	....	6.1	8.5	9.1	10.3	10.5
10	....	8.4	7.3	8.5	10.4	9.3	....	40	....	5.8	8.5	9.2	10.2	10.3
11	....	8.1	7.3	8.5	10.5	9.5	....	41	....	5.0	8.5	9.1	10.5	10.7
12	....	7.8	7.1	8.5	10.8	9.6	....	42	....	4.8	8.5	8.9	10.7	10.6
13	....	7.6	7.2	8.7	11.0	9.5	....	43	....	4.5	8.5	8.7	10.8	10.7
14	....	7.9	7.3	8.6	10.8	9.6	....	44	....	4.4	8.5	8.7	10.7	10.5
15	....	7.7	7.4	8.6	10.8	9.5	....	45	....	4.1	8.5	8.5	10.8	10.6
16	....	7.6	7.4	8.6	11.0	9.7	....	46	....	3.8	8.5	8.7	10.6	10.5
17	....	7.4	7.3	8.9	10.8	9.7	....	47	5.6	3.5	8.4	8.7	10.9	10.4
18	....	7.5	7.4	8.7	10.6	9.8	....	48	5.6	3.9	8.4	9.2	10.5	10.4
19	....	7.4	7.6	8.9	10.5	10.0	....	49	5.8	4.2	8.1	8.5	10.4	10.3
20	....	7.3	7.4	9.0	10.5	10.0	....	50	6.2	4.6	8.1	8.8	10.4	10.2
21	....	6.7	5.7	9.2	10.3	9.9	....	51	6.4	4.7	8.1	8.9	10.2	10.4
22	....	6.5	7.5	9.3	10.2	10.2	....	52	5.9	4.2	8.0	8.9	10.0	10.4
23	....	6.4	7.6	9.4	10.3	10.2	....	53	6.3	4.1	8.3	9.2	10.1	10.4
24	....	6.2	7.6	9.3	10.2	10.1	....	54	6.6	4.2	8.3	9.5	10.2	10.4
25	....	5.3	7.7	9.3	10.2	10.2	....	55	7.2	5.0	8.2	9.7	10.0	10.3
26	....	5.0	7.9	9.5	10.2	10.2	....	56	7.3	5.1	8.2	9.8	10.1	10.2
27	....	5.2	7.7	9.6	10.2	10.2	....	57	7.2	5.4	8.2	9.7	9.7	10.3
28	....	5.1	7.9	9.4	10.2	10.2	....	58	7.5	5.5	8.3	9.7	9.4	10.4
29	....	5.4	7.8	9.2	10.1	10.2	....	59	7.8	5.6	8.3	9.6	9.5	10.4
30	....	5.5	8.2	8.8	10.2	10.3	....	60	8.5	5.6	8.3	9.7	9.6	10.5

TABLE 8.—*Five-minute means of declination (D) at Meanook on June 8, 1918 from 20^h 47^m, June 8 to 2^h, June 9, G. M. T.*
[$D=27°30'$E+tabular value.]

Hour Minute	20^h	21^h	22^h	23^h	24^h	25^h	Hour Minute	20^h	21^h	22^h	23^h	24^h	25^h
m	'	'	'	'	'	'	m	'	'	'	'	'	'
0	....	8.40	5.74	8.28	9.66	9.54	30	....	5.38	8.10	9.04	10.16	10.26
5	....	9.12	6.22	8.28	10.08	9.74	35	....	5.42	8.36	8.74	10.36	10.50
10	....	8.44	7.12	8.46	10.52	9.40	40	....	5.54	8.50	9.02	10.44	10.56
15	....	7.64	7.32	8.68	10.88	9.60	45	....	4.06	8.48	8.66	10.76	10.54
20	....	7.08	7.12	9.02	10.42	9.98	50	5.98	4.32	8.14	8.86	10.30	10.34
25	....	5.62	7.70	9.42	10.22	10.18	55	6.92	4.76	8.24	9.58	10.02	10.32
30	....	5.38	8.10	9.04	10.16	10.26	60	8.40	5.74	8.28	9.66	9.54	10.52

OBSERVATIONS AT THE LUKIAPANG MAGNETIC OBSERVATORY DURING THE SOLAR ECLIPSE OF JUNE 8, 1918.

By J. de Moidrey, S. J.

I beg to transmit a copy of our magnetograms during the eclipse of June 8, 1918, Greenwich civil mean time.[1]

The scale values are for one millimeter of ordinate: $0'.48$ (Declination); 1.87γ (horizontal intensity) and 5.5 to 4.8γ (vertical intensity).

The sensitivity of the balance not being stable, we made two determinations on the 8th and the 10th about 9^h.

Values of the magnetic elements on June 9, at $9^h\ 21^m$ (Coast of China time) are: $D=3^\circ\ 16'.6$ W; $H=33206\gamma$; $Z=33789\gamma$. These values are not absolutely certain. We had observed on the 8th, D and H twice in the forenoon and twice in the afternoon and the inclination with the inductor at about 17^h. But on the 9th there was found under the absolute-measurement room a piece of iron, thrown there a little while before by the masons. We could not make certain whether it was there on the 8th. We therefore repeated the observations on June 10, morning and evening. Unfortunately a strong perturbation had begun about midnight on the 10th. The value of I appearing large, we had it verified by another observer who found it about $2'$ greater still. It is with the aid of all these determinations that we calculated the normal curve as well as we could and then the values of $9^h\ 21^m$.

On the whole the normal values are in good accord. As for the small oscillations which appear here and there on the magnetogram, there is reason to believe, I think, that they are caused by a crew of workmen who were engaged in making repairs.

We expect to make observations during the forthcoming eclipse of the Moon.

[1]The values scaled from the magnetograms by H. W. Fisk and C. C. Ennis of the Department of Terrestrial Magnetism will be found reproduced elsewhere.

A COMPARATIVE STUDY OF MAGNETIC DECLINATION AT AGINCOURT AND MEANOOK DURING 1917.

By W. E. W. Jackson.

In July of 1916 there was established at Meanook, Alberta, a magnetic observatory for the purpose of securing a continuous photographic record of the magnetic declination. The record for the first calendar year was completed on December 31, 1917 and a preliminary analysis of the results obtained is here presented together with a comparative analysis of the results obtained at Agincourt. The Meanook station is located in longitude 113° 21′ W and latitude 54° 37′ N, and the Agincourt station in longitude 79° 16′ W and latitude 43° 47′ N.

At Meanook 105th. mean time is used and at Agincourt, 75th. mean time; the time-clocks are compared daily with chronometers whose errors are allowed to accumulate and whose rates are determined weekly by telegraph. By the addition or subtraction of small weights to the pendulum of the time-clocks they are kept within a few seconds of the true standard time, and they are provided with electrical contrivances to mark the hours on the photographic records.

The ordinates are measured for each hour of the day, and the mean of the 24 hourly values is taken as the mean for the day, and the mean of these means for each day of the month is the mean for the month. The base-line values are determined from absolute declination observations, made weekly. The resultant mean declination for each month of the year at each place is given in Table I; easterly declination is called positive and westerly declination, negative.

Table I.—*Mean Declination at Agincourt and Meanook for 1917.*

Station	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
	° ′	° ′	° ′	° ′	° ′	° ′	° ′	° ′	° ′	° ′	° ′	° ′
Agincourt	— 6 35.4	— 6 35.4	— 6 35.6	— 6 35.8	— 6 35.8	— 6 34.8	— 6 35.4	— 6 36.5	— 6 36.5	— 6 37.0	— 6 37.7	— 6 37.9
Meanook	+27 49.0	+27 48.6	+27 45.9	+27 45.6	+27 43.8	+27 44.2	+27 45.3	+27 45.5	+27 47.0	+27 46.7	+27 45.9	+27 46.0

The range of declination, or the difference between the maximum easterly and westerly movements as recorded in the various months, is given in Table II, columns 2 and 3. There is no periodicity apparent, nor is there any marked parallelism in the ranges at the two places, although generally larger ranges at one place correspond to larger ranges at the other.

Table II.—*Agincourt and Meanook declination ranges in the year 1917.*

Month 1917	Monthly Range		Diurnal Range			
			Means of Extreme Daily Values		Means from Hourly Ordinates	
	Agincourt	Meanook	Ag.	Me.	Ag.	Me.
	° ′	° ′	′	′	′	′
January	1 23.5	2 47.3	22.7	37.9	9.1	9.3
February	0 49.0	1 54.3	17.8	30.8	9.8	7.9
March	0 49.4	1 43.9	19.3	30.8	14.1	11.9
April	0 54.9	4 10.9	22.2	42.9	13.0	15.7
May	0 57.0	2 38.9	23.4	43.4	14.1	18.9
June	1 06.5	1 46.2	21.6	35.8	15.8	19.9
July	0 47.0	4 00.6	21.6	46.2	14.5	21.5
August	3 22.5	4 41.4	41.0	78.6	17.1	19.8
September	1 01.0	2 12.3	22.1	39.0	14.9	15.1
October	1 32.0	3 13.2	24.0	56.3	10.6	14.1
November	0 44.8	2 10.5	16.2	28.9	8.8	8.0
December	1 31.7	2 24.9	18.3	22.6	7.2	7.3

If now we examine *diurnal ranges*, by which we mean the difference between the greatest east and west movement recorded in the 24 hours, we find that from day to day no periodicity is at once apparent in the amplitude. Days of greater disturbance have as a rule greater amplitudes. If however these ranges are meaned for each calendar month we get the result in Table II, columns 4 and 5, in which a maximum occurs in summer and a minimum in winter and certain amount of parallelism is apparent between Agincourt and Meanook, yet the summer values for Meanook are roughly double those of Agincourt, whilst the winter values are only very slightly greater. If the diurnal range is taken from the mean monthly curve obtained by meaning the values at each particular hour of the day, the irregularties due to individual days are greatly diminished and the ranges are then more regular in their progression from season to season at both places (see Table II, columns 6 and 7). The winter values at both are of the same order, and summer values at Meanook are only about 1/3 greater than at Agincourt.

The *diurnal variation* for each month for each hour of the day for Agincourt and Meanook are given in Tables III and IV; + signifies that the magnet points to the east of its mean position, and − to the west. In these tables the standard time at each observatory has been used. In order to show how the diurnal variation appears to be directly dependent on Suntime, the curves have been drawn on Fig. 1 for both places according to their local mean times.

Table III.—*Diurnal variation of magnetic declination at Agincourt for each month during the year 1917.*

75th M. T.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.
h	′	′	′	′	′	′	′	′	′	′	′	′
1	+0.1	+1.9	+1.0	+1.4	+1.0	+0.5	+0.2	+0.3	+0.9	+0.8	−0.4	+0.8
2	−0.3	−0.6	+0.8	+1.6	+0.5	+0.3	+0.1	−2.5	+1.0	+1.2	+0.3	0.0
3	+1.0	+0.4	+1.3	+2.7	+1.1	+0.5	+1.6	−1.9	+1.2	+0.8	+0.6	−0.6
4	+1.7	+0.9	+1.6	+1.8	−0.1	+0.9	+0.4	+1.6	+2.9	+1.4	+1.1	0.0
5	+1.2	+0.4	+1.5	+2.1	+3.5	+3.0	+2.7	+3.8	+3.4	+2.1	+1.8	+0.8
6	+0.9	+1.7	+2.9	+3.7	+5.1	+5.4	+5.7	+6.0	+4.5	+1.4	+2.1	0.0
7	+0.4	+1.8	+4.7	+4.2	+7.1	+7.9	+7.5	+8.4	+6.8	+3.3	+2.3	+1.6
8	+1.4	+3.2	+6.4	+5.4	+7.0	+8.1	+7.2	+8.4	+6.7	+4.1	+3.6	+1.6
9	+3.0	+3.9	+6.1	+4.8	+5.1	+7.0	+6.4	+5.7	+5.5	+4.6	+3.6	+3.0
10	+0.6	+3.1	+3.6	+2.0	+1.7	+3.1	+2.7	+1.0	+2.2	+2.1	+2.7	+3.2
11	−1.4	+1.2	0.0	−2.4	−2.7	−1.8	−1.4	−3.8	−2.6	−1.1	−0.1	+0.9
12	−3.8	−1.9	−4.5	−6.0	−6.3	−5.3	−4.8	−7.1	−6.6	−4.5	−3.2	−1.1
13	−5.2	−4.6	−6.7	−7.2	−6.9	−7.3	−6.9	−8.7	−8.1	−6.0	−4.8	−3.0
14	−4.8	−5.9	−7.7	−7.6	−7.0	−7.7	−7.0	−6.9	−7.9	−5.6	−5.2	−3.9
15	−3.9	−4.9	−6.6	−6.2	−5.7	−6.8	−6.3	−5.4	−5.6	−4.5	−4.0	−4.0
16	−2.4	−3.9	−4.6	−4.6	−4.1	−5.2	−5.4	−2.5	−3.3	−3.4	−3.7	−3.6
17	−1.4	−2.7	−2.7	−2.6	−2.0	−3.0	−3.3	−0.9	−1.5	−2.4	−2.3	−1.8
18	−0.7	−1.6	−1.2	−1.5	−0.5	−1.3	−1.5	+0.3	−0.8	−0.8	−1.3	−1.3
19	+2.2	−0.2	−0.6	−0.6	+0.4	−0.3	−0.4	+2.5	−1.0	+0.3	−0.3	−0.6
20	+2.5	+0.3	+0.1	+0.2	+0.2	−0.4	+0.1	+0.1	−0.4	+0.5	+1.1	+1.3
21	+2.3	+1.4	+1.0	+0.7	+0.6	+0.3	−0.2	+0.1	+0.5	+0.9	+1.5	+1.4
22	+3.9	+2.3	+1.5	+2.4	+0.8	+0.7	+0.3	+1.1	+0.2	+1.9	+1.5	+3.2
23	+2.5	+2.2	+1.3	+3.0	+0.8	+0.6	+1.1	+0.4	+1.0	+2.1	+2.0	+1.3
24	+0.3	+1.9	+0.7	+2.8	+0.5	+0.6	+0.3	+0.4	+1.1	+0.7	+1.1	+0.7
Av. Dep. from Mean	2.0	2.2	2.9	3.2	2.9	3.2	3.1	3.3	3.2	2.4	2.1	1.7

Table IV.—*Diurnal Variation of magnetic declination at Meanook for each month during the year 1917.*

105th M. T.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.
h	′	′	′	′	′	′	′	′	′	′	′	′
1	−0.6	+0.4	+0.2	+1.2	−0.6	−1.6	−0.2	−4.8	−2.9	−0.6	−0.5	−1.8
2	−0.7	+2.2	+1.4	0.0	−3.7	−1.8	−3.1	−3.3	+0.2	+1.8	−0.1	−0.5
3	−1.4	+1.7	+0.7	+1.5	+1.1	−1.9	+0.3	−3.1	+2.0	+2.6	+1.3	+0.5
4	+4.0	+2.3	+1.6	+4.7	+1.7	+1.7	+2.4	+1.8	+3.1	+9.2	+1.0	+3.7
5	+1.0	+1.5	+1.2	+6.5	+3.0	+3.2	+2.4	+4.5	+4.2	+3.5	+1.1	+2.7
6	+4.7	+2.9	+2.0	+5.6	+6.6	+7.2	+7.0	+12.3	+5.4	+5.1	+1.6	+2.0
7	+3.1	+1.9	+2.5	+7.4	+9.2	+10.6	+7.0	+8.7	+7.5	+3.2	+1.3	+0.8
8	+4.4	+2.9	+5.0	+7.2	+11.2	+12.2	+12.4	+12.0	+9.2	+4.6	+3.9	+1.6
9	+4.0	+3.4	+6.8	+7.7	+9.4	+10.4	+13.9	+13.2	+8.7	+5.0	+4.2	+1.5
10	+0.9	+3.3	+7.0	+6.4	+6.4	+8.4	+10.1	+12.6	+7.3	+4.3	+3.6	+2.7
11	−0.2	+2.0	+4.5	+3.0	+3.3	+4.3	+5.4	+4.7	+2.9	+0.7	+1.9	+2.4
12	−2.0	−1.8	+0.7	−0.5	−0.9	+0.8	+0.9	−0.6	−1.6	−2.6	−0.2	+2.3
13	−3.1	−2.4	−1.6	−3.2	−4.7	−2.9	−3.1	−5.0	−4.4	−3.8	−1.6	−0.7
14	−4.6	−2.8	−4.0	−5.2	−6.4	−5.6	−6.9	−6.5	−5.3	−4.3	−2.9	−2.0
15	−4.3	−4.3	−4.9	−6.9	−7.7	−7.7	−7.6	−5.6	−5.9	−4.6	−3.8	−3.6
16	−3.0	−4.2	−4.6	−8.0	−7.3	−7.4	−7.2	−3.7	−5.3	−4.9	−3.2	−2.8
17	−2.8	−4.5	−4.4	−7.6	−6.7	−6.9	−6.7	−5.4	−4.3	−4.3	−3.0	−2.8
18	−1.5	−3.1	−4.1	−7.0	−5.4	−6.8	−5.4	−3.7	−4.5	−3.6	−2.1	−1.9
19	−0.8	−1.3	−3.2	−5.3	−3.8	−4.5	−4.4	−3.0	−4.3	−2.6	−2.1	−1.6
20	+1.6	−1.2	−1.3	−3.7	−2.0	−2.9	−5.4	−6.6	−4.1	−2.8	−0.4	−0.9
21	+0.1	−1.0	−2.2	−0.7	−1.3	−2.6	−5.7	−2.2	−2.0	−1.2	−0.5	+0.5
22	+0.3	−1.0	−1.8	−2.1	−0.4	−2.0	−1.6	−5.6	−2.6	−1.1	+0.7	+0.5
23	+1.2	+0.9	−1.5	−0.5	−1.2	−2.5	−2.3	−5.6	−2.4	−2.6	−0.4	+0.4
24	−0.5	+2.2	−0.5	−0.7	+0.1	−1.8	−2.1	−5.2	−1.0	−1.0	+0.2	−1.2
Av. Dep. from Mean	2.1	2.3	3.0	4.3	4.3	4.9	5.1	5.8	4.2	3.3	1.7	1.6

During the winter months, November to February inclusive, the curves agree very well with each other, but during the summer months, May to August inclusive, both the maximum easterly value and the minimum westerly value are reached about one hour later at Meanook. The amplitude of the easterly swing is about one-third greater at Meanook, but that of the westerly is about the same at the two places. This may be partly due to the greater magnetic latitude of Meanook and possibly also to the longer daylight. For the four summer months May to August, the Sun is above the horizon each day an average of one hour and twenty-six minutes more at Meanook than at Agincourt.

As these diurnal curves are cyclical they may be expressed in Fourier series of the form:

$F = a_1 \sin (\alpha_1 + t) + a_2 \sin (\alpha_2 + 2t) + a_3 \sin (\alpha_3 + 3t) + \ldots$

where $a_1, a_2 \ldots, \alpha_1, \alpha_2 \ldots$ are constants and t is the time counted from 0 hour, expressed in degrees at the rate of one hour to 15°.

If sufficient terms are taken, the error between the computed and observed curves may be reduced to less than any assigned quantity, however small. The curves under consideration for the year 1917 have been grouped according to season for this analysis, winter comprising the four months November, December, January and February, equinox the four months March, April, September and October and summer the remaining four months May, June, July and August. The probable error on any individual hour between the computed and observed curve for the different seasons at Agincourt is less than 0′.2 and for Meanook it is less than 0′.3, whilst the error for the mean of the day is less than 0′.03 for Agincourt and less than 0′.07 for Meanook.

The constants a_1, a_2 etc., are called the amplitudes and the constants α_1, α_2 etc., the phase angles. The values of these quantities are given in Table V; the time of occurrence of maximum in each wave is obtained by making $(\alpha_1 + nt) = 90°$ or 450°, since the sine has its maximum at $90° + 2n\pi$ and this time for the first maximum in each wave is also given.

In the 24-hour wave the phase at Meanook is $2^h\ 33^m$ later than at Agincourt in summer and $2^h\ 8^m$ in winter, the winter times at both places being earlier than in summer. In the 12-hour and 8-hour waves the earlier phase is in the summer at both places, but in the 12-hour wave, although Agincourt is 32 minutes ahead in summer, it is 14 minutes behind in winter, whilst in the 8-hour wave Agincourt is only 9 minutes ahead in summer but 1 hour

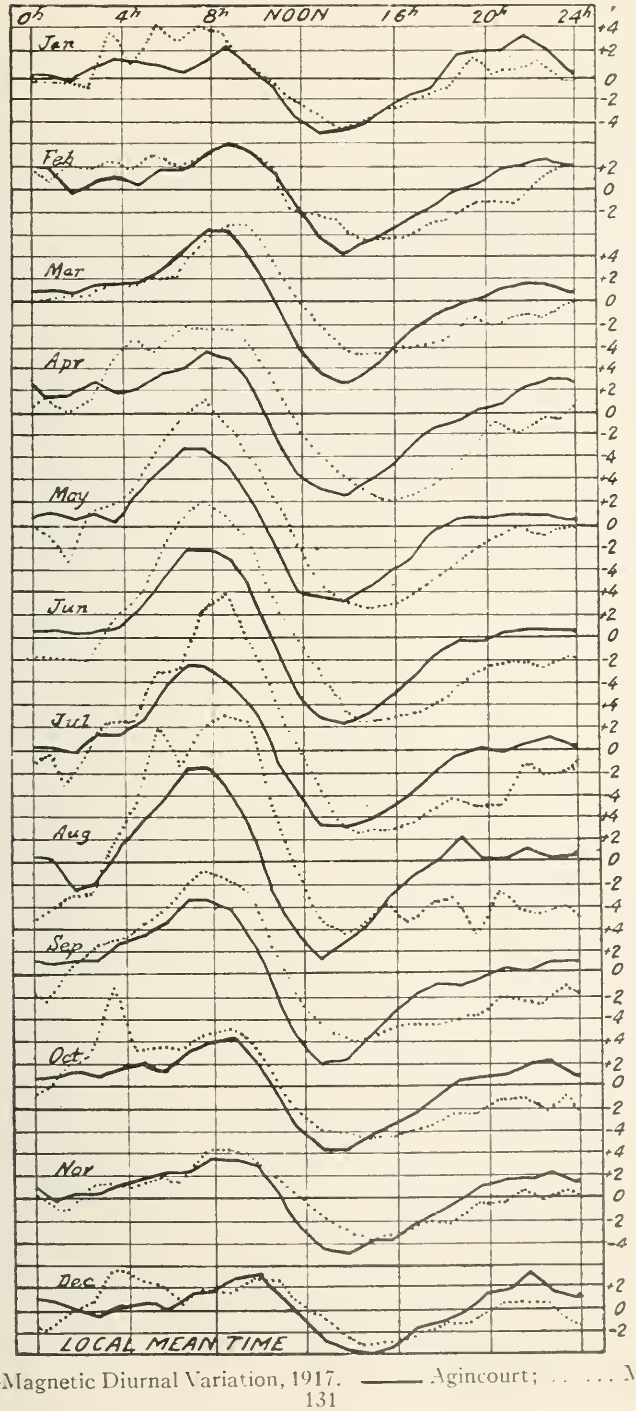


Fig. 1.—Magnetic Diurnal Variation, 1917. ——— Agincourt; . . . . . Meanook.

TABLE V.—*Value of constants in the Fourier series for Agincourt and Meanook seasonal diurnal curves.*

(Percentage values of the amplitudes and local meantime of occurrence of maximum amplitude.)

Season	a_1		a_2		a_3		a_4	
	Ag.	Me.	Ag.	Me.	Ag.	Me.	Ag.	Me.
	′	′	′	′	′	′	′	′
Summer..........	4.0	7.1	4.0	4.3	1.5	1.0	0.2	0.3
Equinox..........	3.8	5.3	3.0	2.1	1.4	0.7	0.5	0.7
Winter...........	2.2	2.6	2.3	1.5	0.5	0.3	0.6	0.4
	Percentage value of amplitudes a							
	%	%	%	%	%	%	%	%
Summer..........	41.3	55.9	41.3	33.9	15.4	7.9	2.0	2.3
Equinox..........	43.7	60.2	34.5	24.0	16.1	8.0	5.7	8.0
Winter...........	39.3	54.2	41.1	31.2	8.9	6.3	10.7	8.3
	α_1		α_2		α_3		α_4	
	°	°	°	°	°	°	°	°
Summer..........	29.2	351.2	228.0	211.8	87.2	79.6	360.4	241.0
Equinox..........	38.9	4.6	217.9	207.9	65.6	17.2	251.4	266.9
Winter...........	48.9	17.2	197.0	203.7	40.8	331.6	227.1	236.4
	Local Mean Time of Occurrence of Maximum							
	h m	h m	h m	h m	h m	h m	h m	h m
Summer..........	4 03	6 36	7 24	7 56	0 04	0 13	1 30	3 29
Equinox..........	3 24	5 40	7 41	8 04	0 32	1 37	3 19	3 03
Winter...........	2 44	4 52	8 26	8 12	1 05	2 12	3 43	3 34

and 7 minutes in winter. The 6-hour wave is more erratic in phase, particularly in summer, when its amplitude is very small, but at both places the phase is later in winter.

The amplitudes of the first two waves are the important ones at both places. If the amplitudes are expressed in percentages it is seen that the 24-hour and 8-hour waves are most effective at the equinoxes and that the 12-hour wave is most effective in summer and the 6-hour wave in winter. At Agincourt the 24-hour and 12-hour waves are about equal value and account for about 80% of the amplitude, whilst in Meanook the 24-hour wave is about double the 12-hour wave and yet together they account for about 86% of the total amplitude. The Meanook diurnal curve approaches nearer a single sine-wave of 24 hours period than does the diurnal curve at Agincourt.

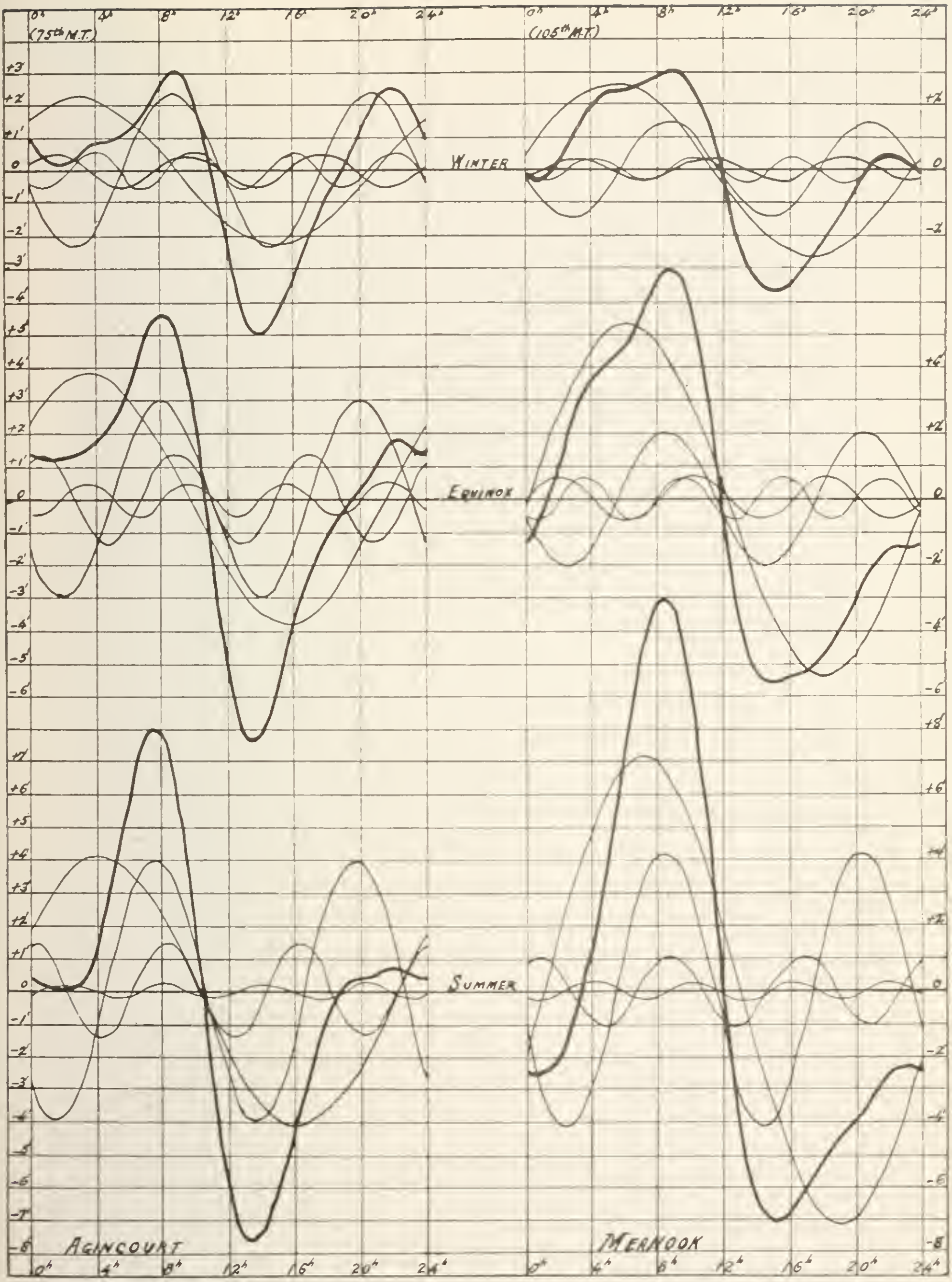


Fig. 2.—Seasonal Diurnal Curves and Harmonics.

On Fig. 2 is shown graphically the seasonal diurnal curves for each station in heavy line and the first 4 harmonics in light lines.

In addition to these regular daily movements there are also recorded what are known as magnetic disturbances. These do not occur at any apparent regular intervals in any year nor do they show similar movements at similar local times, but usually at the same absolute time the movements are more or less synchronous and in the larger storms obscure completely the daily movement.

In Fig. 3 examples of different types of disturbance are reproduced. In cases I and II that type of disturbance having a sudden commencement occurring at the same instant of absolute time is shown. A small westerly movement is followed by a much larger easterly movement at both stations, and the disturbance is immediately in full progress. In case III at Agincourt there is a rather leisurely movement of the magnet whilst at Meanook we have a sudden increase at $8^h\ 30^m$ G. M. T. followed by a storm with very large and rapid fluctuations which, on the average, have carried the magnet in the opposite direction to the movement at Agincourt. In cases IV to VII is shown the type of disturbance which is usually of short duration and produces what is known as a bay in the magnetic curve. There is very often a recurrence of this bay on the following day at about the same time as shown in case IV. Case V shows the bay in the opposite direction at the two places. In case VI the bay is westerly, but while a smooth curve is recorded at Agincourt, it is serrated at Meanook. In case VII the bay is easterly. In case VIII a magnetic storm of large amplitude is shown for Meanook with practically no corresponding movement at Agincourt.

METEOROLOGICAL SERVICE, *Toronto, Canada, June 1, 1918.*

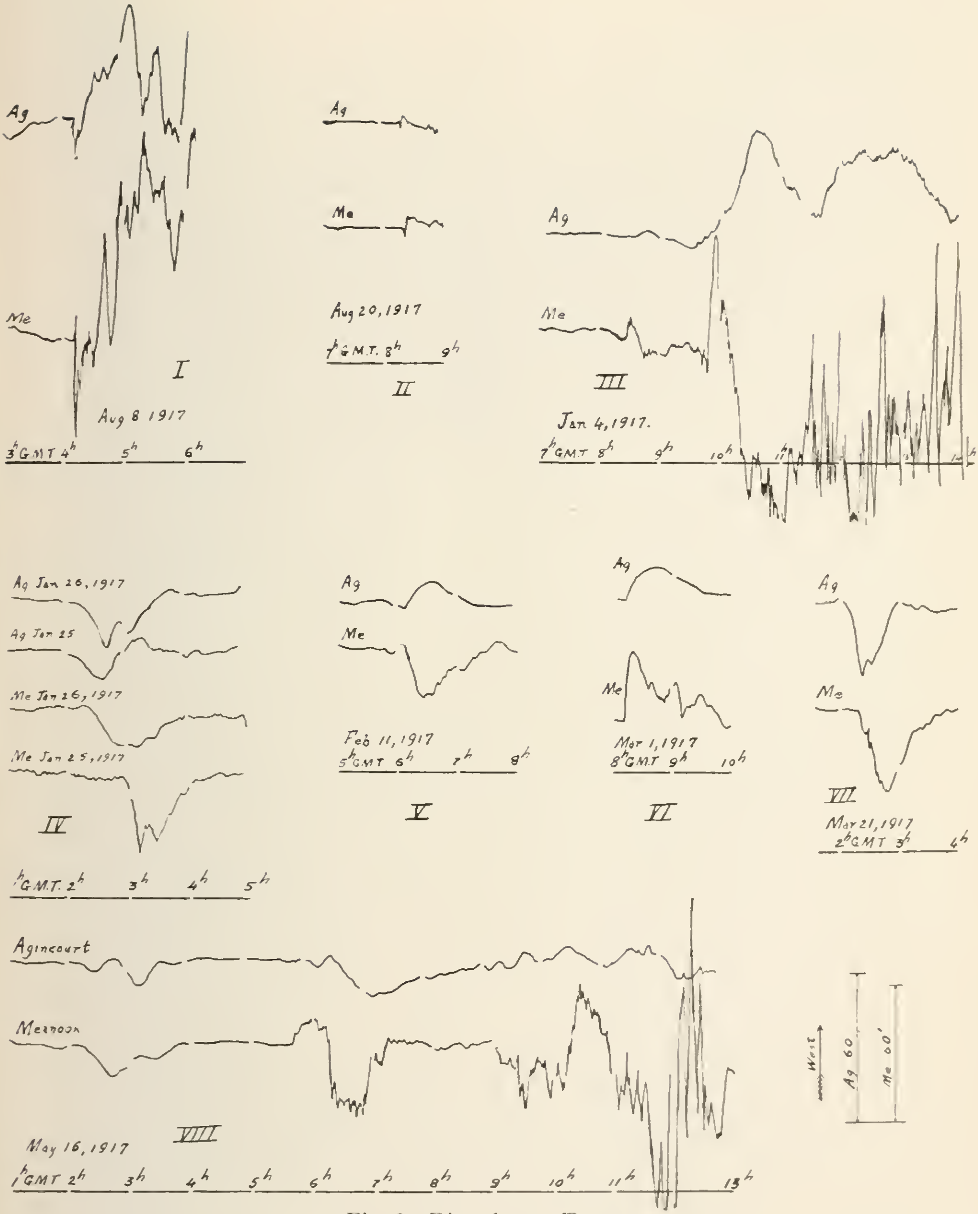


Fig. 3—Disturbance Types.

WOLFER PROVISIONAL SUN-SPOT NUMBERS FOR JANUARY, 1916, TO MARCH, 1918.

Communicated By G. van Dijk.[1]

Day of Month	1916 January	February	March	April	May	June	July	August	September	October	November	December
1	51	88	....	103	105	38	56	36	22	7	61	....
2	....	91	64	137	103	23	....	30	15	0	73	....
3	60	66	76	144	92	25	56	22	16	....	76	....
4	85	47	....	142	104	....	39	14	....	17	112	51
5	....	64	....	142	70	54	....	22	28	27	....	69
6	....	....	97	109	80	35	35	49	....	36	122	41
7	76	76	76	73	72	24	....	35	43	73	112	....
8	66	....	94	76	51	14	43	43	....	110	....	....
9	38	74	....	68	56	8	25	14	38	133	....	....
10	....	98	76	70	53	34	....	....	49	94	....	59
11	29	84	....	71	68	28	16	28	49	106	....	67
12	25	....	47	59	58	34	7	38	59	111	....	....
13	....	74	....	....	29	23	8	32	83	112	....	....
14	....	....	14	57	....	37	14	47	76	100	44	41
15	23	....	32	60	....	35	13	55	83	77	58	....
16	....	46	49	47	56	38	15	50	77	63	46	17
17	29	29	61	46	40	46	28	....	73	62	49	....
18	....	38	80	39	40	41	34	....	....	....	....	53
19	31	....	37	37	50	58	45	64	....	....	8	....
20	....	43	42	25	50	90	....	90	75	....	8	27
21	25	62	....	40	61	109	103	75	....	....	....	7
22	47	....	79	38	68	137	128	47	42	8	47	14
23	43	....	97	....	89	171	125	38	20	....	65	....
24	23	....	....	26	87	174	....	10	14	20	....	56
25	40	21	91	67	107	182	137	0	8	19	....	31
26	....	26	89	74	125	126	117	0	22	27	....	....
27	65	19	72	68	....	115	109	0	18	21	....	....
28	51	36	71	70	....	112	60	17	25	....	30	....
29	34	26	....	79	80	85	61	24	18	43	....	....
30	....		52	86	62	66	30	10	....	33	....	....
31	....		....		....		22	....		44		....
Means	44.3	55.4	66.5	73.3	71.4	67.7	53.0	34.1	41.4	56.0	60.7	41.0

Mean for 1916: 55.4

Day of Month	1917 January	February	March	April	May	June	July	August	September	October	November	December	1918 January	February	March
1	....	48	....	....	134	137	107	114	120	44	84	116	56	....	....
2	67	....	47	26	92	109	104	88	....	61	79	136	....	....	25
3	....	58	99	....	112	73	100	94	83	47	97	140	....	....	31
4	43	72	132	15	120	88	110	107	92	37	80	83	65	48	46
5	58	....	....	7	98	65	....	133	117	56	73	62	80	....	31
6	72	90	132	....	....	74	112	199	103	65	....	56	50	25	31
7	112	....	....	24	94	79	148	268	80	68	85	61	....	29	....
8	....	99	....	7	68	86	....	262	65	58	104	74	....	24	55
9	94	104	107	14	59	101	....	172	80	....	80	48	65	26	52
10	....	121	93	13	57	99	....	244	84	....	94	....	....	20	62
11	....	122	110	28	76	125	165	248	71	....	72	....	92	67	103
12	90	116	....	76	89	139	218	243	....	39	....	116	54	85	136
13	91	116	....	....	94	140	152	225	75	61	....	148	....	89	107
14	....	....	92	149	95	140	137	234	106	....	56	154	84	....	106
15	51	98	....	....	91	127	103	210	99		65	161	....	80	....
16	....	95	86	....	110	148	119	172	97	51	89	....	....	94	104
17	....	97	95	....	140	163	129	139	119	....	97	151	195	113	111
18	....	....	89	110	121	149	76	141	140	73	....	....	....	112	106
19	....	....	82	107	161	143	79	125	149	....	99	....	103	86	103
20	....	58	77	74	118	91	67	98	182	....	....	....	108	90	97
21	....	....	77	68	93	95	55	105	209	....	....	....	107	....	64
22	....	....	54	....	121	82	....	100	207	77	121	....	116	43	38
23	....	19	54	103	138	92	74	80	206	118	100	....	....	....	58
24	....	31	....	88	138	107	94	64	208	137	122	....	114	....	65
25	....	14	....	....	160	102	131	65	208	....	....	....	138	....	80
26	....	25	115	102	136	107	120	91	173	118	....	....	96	56	83
27	95	23	84	96	163	135	121	76	128	103	115	179	91	55	82
28	....	29	....	64	170	163	122	83	69	....	....	147	97	....	60
29	83		63	58	143	136	145	81	85	65	....	141	119		62
30	....		80	108	91	119	135	84	59	....	....	130	....		53
31	58		50		100		....	94		75		....	....		70
Means	76.2	71.8	86.6	63.7	112.7	113.8	117.0	143.2	121.9	71.4	90.1	116.8	96.3	83.4	72.2

Mean for 1917: 98.8

[1]Derived from the *Meteorologische Zeitschrift.*

RESULTS OF OBSERVATIONS MADE DURING THE SOLAR ECLIPSE OF JUNE 8, 1918 AT THE MAGNETIC OBSERVATORY AT ANTIPOLO, MANILA.

By M. Saderra Masó, S. J.

Chief of Magnetic and Seismological Divisions, Weather Bureau.

Table 1 shows the magnetic elements as well as the meteorological conditions, during the eclipse of June 8, 1918. The magnetic ordinates were read from the photographic records with the greatest accuracy every five minutes; the values of the base lines are only approximate. At the time the daily mean absolute values of the different magnetic elements were:
Declination, $D = 0° \; 34'.09$ E; Horizontal Intensity, $H = 38110\gamma$; Vertical Intensity, $Z = 10975\gamma$.

The air temperature, wind direction and force were also taken from the recording instruments. The geographic position of the observatory is: Latitude: 14° 35′ 48″ N; Longitude: 121° 10′ E. of Gr.; Standard time: 8^{h} E. of Greenwich.

Table 1.—*Magnetic elements and meteorological conditions at Antipolo, June 8, 1918.*

G.M.T. June 8	Declination	Hor. Int.	Vert. Int.	Air temperature	Wind		Weather
					Direction	Force	
h m	° ′	γ	γ	°		0-12	
19 25	0 34.32 E	38094	10981	23.6	ENE	1	Clear
30	34.32	094	981	23.6	Calm		
35	34.32	094	981	23.5	Calm		
40	34.18	094	983	23.5	Calm		
45	34.04	095	981	23.4	Calm		
50	34.04	095	981	23.4	Calm		
55	34.04	096	980	23.4	Calm		
20 00	34.04	095	980	23.3	Calm		E horizon cloudy
05	34.04	095	979	23.3	NE	1	
10	34.04	094	979	23.2	NE	1	
15	34.04	093	979	23.2	NE	1	
20	34.04	092	977	23.2	NE	1	
25	34.18	093	977	23.1	Calm		
30	34.32	093	977	23.1	Calm		
35	34.32	094	979	23.1	Calm		
40	34.47	094	979	23.1	NE	1	
45	34.47	093	977	23.2	NE	1	
50	34.47	094	977	23.2	NE	1	
55	34.47	096	977	23.2	NE	1	

TABLE 1.—*Magnetic elements and meteorological conditions at Antipolo.—Continued.*

G.M.T. June 8	Declination	Hor. Int.	Vert. Int.	Air temperature	Wind		Weather
					Direction	Force	
h m	° ′	γ	γ	°		0-12	
21 00	34.47	096	977	23.2	Calm		E horizon cloudy
05	34.47	094	976	23.2	Calm		
10	34.47	093	975	23.2	Calm		
15	34.61	092	976	23.2	Calm		
20	34.75	093	976	23.2	NE	1	
25	34.90	091	976	23.2	NE	1	
30	35.04	092	977	23.3	NE	1	
35	35.04	092	976	23.3	NE	1	
40	35.18	093	976	23.3	Calm		
45	35.33	092	976	23.3	Calm		
50	35.47	095	976	23.3	NE	1	
55	35.61	096	975	23.4	NE	1	
22 00	35.61	097	974	23.4	NE	1	Clear
05	35.61	098	974	23.5	NE	1	
10	35.61	098	972	23.6	Calm		
15	35.75	099	971	23.7	NE	1	
20	35.75	100	971	23.8	NE	1	
25	35.75	101	970	23.9	NE	1	
30	35.75	101	970	24.1	NE	1	
35	35.75	101	969	24.2	NE	1	
40	35.90	101	967	24.4	NE	1	
45	35.90	101	966	24.5	NE	1	
50	35.90	101	965	24.9	Calm		
55	35.75	101	964	25.3	ENE	1	
23 00	35.75	101	962	25.7	ENE	1	Clear
05	35.75	101	962	25.8	ENE	1	
10	35.75	101	962	26.1	ENE	1	
15	35.61	101	961	26.4	Calm		
20	35.61	102	961	26.7	Calm		
25	35.61	102	961	26.8	ENE	1	
30	35.61	103	961	26.7	ENE	2	
35	35.61	104	961	26.8	ENE	2	
40	35.47	104	961	27.1	ENE	2	
45	35.47	103	960	27.3	ENE	2	
50	35.47	102	960	27.3	ENE	2	
55	35.33	102	960	27.6	ENE	2	
24 00	35.33	102	960	27.8	ENE	1	Cloudy
05	35.33	102	960	27.9	ENE	2	
10	35.33	102	960	28.0	ENE	2	
15	35.33	102	960	28.1	E	2	
20	35.33	103	959	28.4	E	2	
25	35.33	103	959	28.7	E by S	2	
30	35.33	104	959	29.1	ESE	2	
35	35.18	104	957	29.2	ESE	2	
40	35.18	105	957	29.1	ESE	2	
45	35.04	106	959	29.0	ESE	2	
50	35.04	107	959	29.2	ESE	2	Cloudy

PRELIMINARY RESULTS OF OCEAN MAGNETIC OBSERVATIONS ON THE CARNEGIE FROM CRISTOBAL TO NEWPORT NEWS AND WASHINGTON, D. C., MAY AND JUNE, 1918.[1]

By H. M. W. Edmonds, Commanding the *Carnegie*.

(Observers: H. M. W. Edmonds, A. D. Power, B. Jones, L. L. Tanguy, J. M. McFadden, and W. E. Scott.)

Date	Latitude	Long. East of Gr.	Carnegie Values			Chart Differences[2]					
						Decl'n and Incl'n			Hor. Int.[3]		
			Decl'n	Incl'n	Hor. Int.	Brit.	Ger.	U.S.	Br.	Gr.	U.S.
1918	° ′	° ′	°	°	c.g.s.	°	°	°			
May 12	10 30 N	280 29	......	38.4 N	.320	3.6 N	3.1 N	.....	−9	−11	−20
12	10 41 N	280 33	4.5 E	......	......	0.2 E	0.2 E	0.3 E	....	....	....
13	11 07 N	280 33	4.5 E	......	......	0.3 E	0.3 E	0.3 E	....	....	....
13	11 58 N	280 24	......	40.4 N	.318	3.2 N	2.9 N	.....	−9	−12	−20
13	12 11 N	280 25	4.3 E	......	......	0.3 E	0.3 E	0.3 E	....	....	....
14	13 03 N	280 19	4.2 E	......	......	0.4 E	0.4 E	0.4 E	....	....	....
14	13 41 N	280 11	......	42.9 N	.314	2.7 N	2.7 N	.....	−11	−15	−22
14	13 54 N	280 07	4.0 E	......	......	0.3 E	0.3 E	0.4 E	....	....	....
15	13 49 N	280 11	4.0 E	......	......	0.3 E	0.3 E	0.4 E	....	....	....
15	14 09 N	279 23	......	43.4 N	.314	2.3 N	2.7 N	.....	−11	−15	−23
15	14 19 N	279 10	4.2 E	......	......	0.3 E	0.4 E	0.3 E	....	....	....
16	15 30 N	278 45	4.6 E	......	......	0.8 E	0.8 E	0.8 E	....	....	....
16	16 12 N	278 24	......	46.0 N	.310	1.9 N	2.9 N	.....	−12	−17	−24
16	16 27 N	278 16	4.2 E	......	......	0.4 E	0.4 E	0.6 E	....	....	....
17	17 34 N	277 41	4.3 E	......	......	0.5 E	0.5 E	0.7 E	....	....	....
17	18 14 N	277 10	......	48.6 N	.306	1.9 N	2.9 N	.....	−13	−18	−25
17	18 31 N	277 00	4.2 E	......	......	0.3 E	0.4 E	0.6 E	....	....	....
18	19 35 N	276 33	4.6 E	......	......	0.8 E	0.8 E	1.0 E	....	....	....
18	20 26 N	276 05	......	51.1 N	.300	2.0 N	3.0 N	.....	−15	−21	−25
18	20 40 N	275 53	4.6 E	......	......	0.7 E	0.8 E	0.8 E	....	....	....
19	21 06 N	275 02	4.9 E	......	......	0.7 E	1.0 E	0.8 E	....	....	....
19	21 30 N	274 34	......	52.1 N	.300	1.9 N	3.2 N	.....	−13	−18	−22
19	21 40 N	274 24	4.7 E	......	......	0.3 E	0.6 E	0.4 E	....	....	....
20	22 59 N	273 48	5.2 E	......	......	0.7 E	1.0 E	0.6 E	....	....	....
20	23 48 N	273 43	......	54.8 N	.290	1.6 N	2.8 N	.....	−17	−18	−22
20	23 49 N	273 50	4.6 E	......	......	0.2 E	0.4 E	0.0	....	....	....
21	23 15 N	274 28	5.0 E	......	......	0.8 E	1.1 E	0.6 E	....	....	....
21	24 04 N	274 44	......	55.2 N	.286	1.3 N	2.2 N	.....	−18	−18	−24
21	24 19 N	274 49	4.7 E	......	......	0.7 E	0.9 E	0.5 E	....	....	....
May 22	23 44 N	275 44	4.4 E	......	......	0.8 E	0.9 E	0.6 E	....	....	....
22	23 33 N	276 12	......	55.2 N	.288	2.0 N	2.4 N	.....	−17	−17	−24

[1]For previous table, see *Terr. Mag.*, v. 23, pp. 69-72.

[2]Charts used for comparison: U. S. Hydrographic Office Chart No. 2406 for 1915 and No. 1701 for 1900; British Admiralty Charts No. 3777 for 1917, Nos. 3598 and 3603 for 1907; Reichs-Marine-Amt Charts Tit. XIV, No. 2 for 1910, Tit. XIV, Nos. 2a and 2b for 1905. The chart differences are obtained by subtracting corrected chart values, derived as explained in previous sentence, from the observed *Carnegie* values. The letter E signifies that the chart value for east declination is smaller, or the chart value for west declination larger, than the *Carnegie* value; W signifies the reverse. The letter N signifies that the derived chart value for northerly inclination is smaller, or for southerly inclination larger, than the *Carnegie* value; S signifies the reverse. The plus sign signifies that the derived chart value for horizontal intensity is smaller than the *Carnegie* value, the minus sign meaning, of course, the reverse.

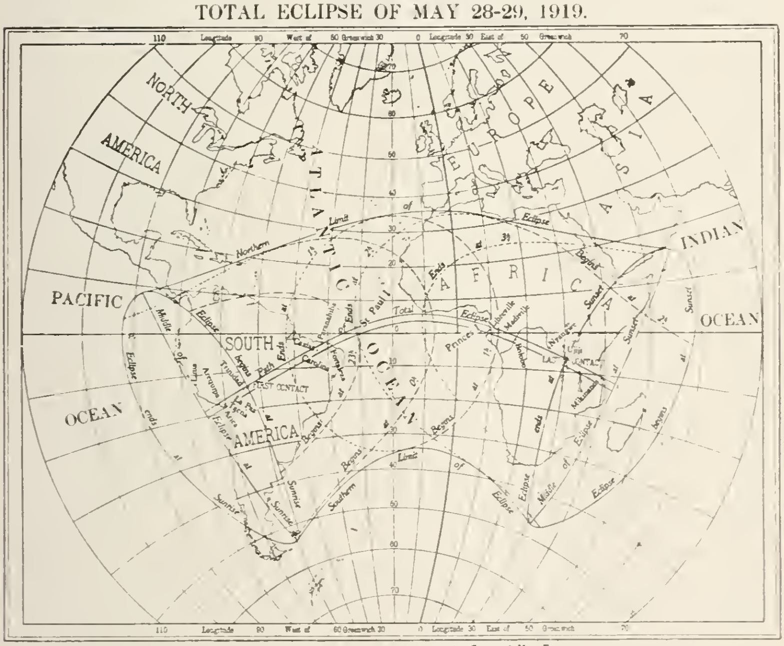
[3]Expressed in units of third decimal C. G. S.

Date	Latitude	Long. East of Gr.	Carnegie Values			Chart Differences					
			Decl'n	Incl'n	Hor. Int.	Decl'n and Incl'n			Hor. Int.		
						Brit.	Ger.	U.S.	Br.	Gr.	U.S
1918	° ′	° ′	°	°	c.g.s.	°	°	°			
22	23 50 N	276 11	4.1 E	...	...	0.7 E	0.7 E	0.5 E	...	...	...
23	23 37 N	277 02	3.9 E	...	...	0.8 E	0.8 E	0.6 E	...	...	...
23	23 53 N	277 10	...	55.7 N	.283	1.7 N	2.6 N	...	−19	−20	−26
23	23 37 N	277 27	3.1 N	...	...	0.3 E	0.3 E	0.0	...	...	...
24	23 40 N	278 21	...	55.5 N	.283	1.5 N	2.3 N	...	−19	−19	−27
24	23 48 N	278 28	3.0 N	...	...	0.6 E	0.8 E	0.5 E	...	...	...
25	24 27 N	279 17	...	56.8 N	.278	1.6 N	2.7 N	...	−19	−20	−27
25	24 44 N	279 25	2.5 E	...	...	0.7 E	0.9 E	0.8 E	...	...	...
26	25 04 N	280 00	2.2 E	...	...	0.8 E	0.9 E	0.9 E	...	...	...
26	25 35 N	280 11	...	58.2 N	.272	1.8 N	2.3 N	...	−18	−20	−27
26	26 10 N	280 13	1.5 E	...	...	0.4 E	0.4 E	0.7 E	...	...	...
27	28 11 N	280 17	0.7 E	...	...	0.5 E	0.0	0.7 E	...	...	...
27	29 01 N	280 08	...	61.9 N	.255	1.9 N	1.6 N	...	−19	−21	−23
27	29 25 N	280 10	0.4 E	...	...	0.4 E	0.2 E	0.6 E	...	...	...
28	30 26 N	280 49	0.1W	...	...	0.5 E	0.4 E	0.7 E	...	...	...
28	30 44 N	281 04	...	63.6 N	.244	2.0 N	1.3 N	...	−21	−23	−22
28	30 50 N	281 10	1.0W	...	...	0.0	0.1W	0.3 E	...	...	...
29	31 09 N	281 41	1.4W	...	...	0.0	0.1W	0.3 E	...	...	...
29	31 14 N	281 52	...	63.8 N	.242	1.3 N	1.0 N	...	−18	−22	−18
29	31 18 N	281 55	1.4W	...	...	0.2 E	0.1W	0.5 E	...	...	...
30	31 42 N	282 05	1.3W	...	...	0.5 E	0.4 E	0.8 E	...	...	...
30	31 54 N	282 22	...	64 8 N	.255	1.8 N	1.5 N	...	−19	−23	−21
30	32 00 N	282 32	2.0W	...	...	0.3 E	0.3 E	0.8 E	...	...	...
31	32 28 N	283 24	2.8W	...	...	0.2 E	0.0	0.8 E	...	...	...
31	32 52 N	284 15	...	65.5 N	.230	1.4 N	0.8 N	...	−17	−18	−15
31	33 01 N	284 33	4.4W	...	...	0.4W	0.8W	0.0	...	...	...
June 1	33 43 N	285 16	4.9W	...	...	0.1W	0.5W	0.1 E	...	...	...
1	33 54 N	285 39	...	66.7 N	.221	1.5 N	1.0 N	...	−18	−20	−16
1	33 54 N	285 43	5.4W	...	...	0.2W	0.7W	0.2W	...	...	...
2	34 08 N	286 07	5.6W	...	...	0.0	0.3W	0.3 E	...	...	...
2	34 46 N	285 51	...	67.4 N	.216	1.3 N	0.8 N	...	−17	−16	−16
2	35 10 N	285 45	6.3W	...	...	0.4W	0.7W	0.2W	...	...	...
3	36 02 N	285 29	6.9W	...	...	0.7W	1.0W	0.7W	...	...	...
3	36 07 N	285 04	...	68.4 N	.209	1.0 N	0.7 N	...	−13	−14	−16
3	36 09 N	284 49	5.7W	...	...	0.1 E	0.1W	0.0	...	...	...
4	36 11 N	284 34	5.8W	...	...	0.2W	0.4W	0.4W	...	...	...
8	37 19 N	283 51	6.2W	...	...	0.4W	0.5W	0.6W	...	...	...
9	38 12 N	283 44	6.2W	...	...	0.1W	0.2W	0.2W	...	...	...
9	38 13 N	283 44	...	70.1 N	.196	0.6 N	0.4 N	...	−12	−12	−12
10	38 14 N	283 07	6.0W	...	...	0.4W	0.3W	0.5W	...	...	...

NOTES

7. Circumstances of the Solar Eclipse of May 29, 1919. Early attention is called to the desirability that favorably-situated stations take advantage of a favorable opportunity to arrange for important magnetic, electric and allied observations during the solar eclipse of May 29, 1919. Unfortunately no magnetic observatories are actually situated in the belt of totality, however, the observatories at Rio Janeiro and Pilar are within the region of possible effects. The Department of Terrestrial Magnetism hopes to send two expeditions to favorable points. It will be advantageous if others who propose to send expeditions will communicate their plans to the editor of this journal as soon as possible. Fig. 1 shows the region of visibility of the eclipse. The duration of totality is exceptionally long (6 seconds or more).

TOTAL ECLIPSE OF MAY 28-29, 1919.



Note:- The hours of beginning and ending are expressed in Greenwich Mean Time.

	Greenwich Civil Mean Time				Longitude from Greenwich		Latitude	
		d	h	m	°	′	°	′
Eclipse begins	May	29	10	33.5	+63	27	−14	06
Central eclipse begins		29	11	30.1	+75	09	−19	43
Central eclipse at local apparent noon		29	13	06.6	+17	23	+ 4	18
Central eclipse ends		29	14	47.4	−42	27	−12	25
Eclipse ends		29	15	44.0	−30	36	− 6	46

8. Principal Magnetic Storms Cheltenham Magnetic Observatory, April to June, 1918, (Lat. 38° 44.0′ N, Long. 76° 50.5′ W.)[1]

Greenwich Mean Time		Range		
Beginning	Ending	Declination	Hor. Int.	Ver. Int.
h m	h m	′	γ	γ
Apr. 5, 22 00	Apr. 7, 5 ..	56.7	132	135
May 16, 19 00	May 17, 9 ..	41.4	223	250
June 9, 19 ..	June 11, 3 ..	39.0	274	212

9. Concerning Magnetic Observatories. The Argentine corvette *Uruguay* left Buenos Aires on February 18 with a new staff for the *meteorological and magnetic station on Laurie Island,* to replace those whose time has expired. The chief of the Argentine Commission is Señor Ole Holm, who, together with another member, has already seen service on the island. Continuous hourly eye observations have now been maintained since March, 1903, at this most southern observatory in the world. (See December issue.)

Mr. Wiggin, director of the Argentine Meteorological Service, is making every effort to establish a new magnetic observatory at La Quiaca, in Argentina near the Bolivian frontier. The buildings were already partially completed in 1917 and are located on the grounds of the Argentine Meteorological Station at *La Quiaca.* In May, 1917, the director succeeded in obtaining an additional grant from the Argentine government for the completion of the buildings. (See December issue.)

During the stay of the *Carnegie* party at New Zealand in Nov., 1915, they were informed by Director Skey, of the Christchurch Magnetic Observatory, that a new magnetic observatory had been established at Amberley, a small town about 30 miles north of Christchurch. The new observatory was not then in full operation but magnetograms of the three magnetic elements were being obtained. In order to properly connect the work of the two observatories, they were to be operated together for a year or more. Disturbances at the Christchurch Observatory due to electric car lines made the establishment of a new observatory necessary.

No money has yet been made available for the erection of the new magnetic observatory in *South Australia* on an undisturbed site. In the meantime the tramway disturbance at the *Melbourne Observatory* is continually increasing in magnitude, and is so serious that probably no use can be made of the vertical-intensity records.

In spite of delays, resulting from various causes, it is hoped that the magnetic observatory of the Carnegie Institution of Washington at *Watheroo,* in Western Australia, situated about 120 miles north of Perth, will be in operation by 1919.

10. Personalia. Sir Napier Shaw delivered the Halley lecture at Oxford University on May 28, 1918, his subject being, "The first chapter in the story of the winds." *Prof. Horace Lamb* has been appointed Halley lecturer at Oxford University for 1919. *Dr. T. C. Mendenhall* was awarded the medal of the Franklin Institute at Philadelphia on May 15, 1918, the other recipient being *Senator G. Marconi.*

[1] Communicated by *E. Lester Jones,* Superintendent, Coast and Geodetic Survey; *Geo. Hartnell,* Observer-in-charge.

LETTERS TO EDITOR

INSTRUCTIONS ISSUED BY FRANCE AND UNITED STATES CONCERNING PROTECTION OF COOK'S THIRD EXPEDITION, RETURNING TO ENGLAND.

The following extracts from Arthur Kitson's book "Captain James Cook, R. N., F. R. S. The Circumnavigator," pages 355-356, will be of interest[1]:

"It may conveniently be noted here that, on the arrival of the *Resolution* and *Discovery* at Macao, on their way home in 1780, they were informed that England was at war with France and the American colonies; so to preserve a record for the Admiralty in case of capture, Burney made a copy of the whole of his log on thin Chinese paper. This copy is in the British Museum, and is written on both sides of sheets of paper, folded many times, in a clear hand, but so small as almost to require a magnifying glass to decipher it. This precaution was in reality unnecessary, for on the declaration of war the French Minister, M. de Sartines, wrote the following instructions to the Navy:

'Captain Cook, who sailed from Plymouth in July, 1776, on board the *Resolution,* in company with the *Discovery,* Capt. Clerke, in order to make some discoveries on the coasts, islands and seas of Japan and California, being on the point of returning to Europe, and as such discoveries are of general utility to all nations, it is the King's pleasure that Capt. Cook shall be treated as a commander of a neutral and allied power, and that all Captains of armed vessels, etc., who may meet that famous navigator, shall make him acquainted with the King's order on this behalf, but at the same time let him know that on his part he must refrain from all hostilities.

"Fiske in his 'American Revolution' also says:

'When Franklin was in Paris as representative of the United States he was empowered to issue Letters of Marque against the English, but in doing so, inserted an instruction that if any of the holders should fall in with vessels commanded by Captain Cook, he was to be shown every respect and be permitted to pass unattacked on account of the benefits he had conferred on mankind through his important discoveries.'

The Royal Society of London later made recognition of the courtesies thus shown to Cook's Expedition. Quoting from the book on "The Life of Captain James Cook," by A. Kippis, London, 1788, page 512:

"Of the gold medals which were struck on this occasion, one was presented to His Majesty, another to the Queen and a third to the Prince of Wales. Two were sent abroad, the first to the French King, on account of the protection he had granted to the ships under the command of Captain Cook; and a second to the Empress of Russia, in whose dominions the same ships had been received and treated with every degree of friendship and kindness." After the general assignment of these medals in 1784, one was also bestowed upon Franklin.

[1] See June 1918 issue of this Journal, p. 45.

According to the Marquis of Condorcet, the French measure "originated in the liberal and enlightened mind of that excellent citizen and statesman, Monsieur Turgot." The original text of the passage[1] from *Condorcet's Life of Turgot,* is as follows:

"Dans le moment où la guerre se déclara, M. Turgot vit combien il seroit honorable à la Nation Francoise que le vaisseau de Cook fût respecté sur les mers. Il dressa un Mémoire pour exposer les motifs d'honneur, de raison, d'intérêt même qui devoient dicter cet acte de respect pour l'humanité; & c'est sur son Mémoire, dont pendant toute sa vie l'auteur est resté inconnu, qu'a été donné l'ordre de ne pas traiter en ennemi le bienfaiteur commun de toutes les nations européennes."

Kippis on pages 477-478 of the work cited, makes the statement that the American Congress did not support Franklin's action; however, no evidence has been found for this assertion. The instructions issued by Franklin 9 days prior to those of M. de Sartines, are as follows:

PASSPORT FOR CAPTAIN COOK.[2]

To all Captains and Commanders of armed Ships acting by Commission from the Congress of the United States of America, now in War with Great Britain.

Gentlemen,

A Ship having been fitted out from England before the commencement of this War, to make Discoveries, of new Countries, in Unknown Seas, under the Conduct of that most celebrated Navigator and Discoverer, Captain Cook; an Undertaking truly laudable in itself, as the Increase of Geographical Knowledge facilitates the Communication between distant Nations, in the Exchange of useful Products and Manufactures, and the Extension of Arts, whereby the common Enjoyments of human Life are multiply'd and augmented, and Science of other kinds encreas'd to the Benefit of Mankind in general; This is therefore most earnestly to recommend to every one of you, that in case the said Ship, which is now expected to be soon in the European Seas on her Return, should happen to fall into your Hands, you would not consider her as an Enemy, nor suffer any Plunder to be made of the Effects contain'd in her, nor obstruct her immediate Return to England, by detaining her or sending her into any other Part of Europe or to America, but that you would treat the said Captain Cook and his People with all Civility and Kindness, affording them, as common Friends to Mankind, all the Assistance in your Power, which they may happen to stand in need of. In so doing you will not only gratify the Generosity of your own Dispositions, but there is no doubt of your obtaining the Approbation of the Congress, and your other American Owners. I have the honour to be, Gentlemen, your most obedient humble Servant.

Given at Passy, near Paris, this 10th day of March, 1779.

B. FRANKLIN,
Plenipotentiary from the Congress of the United States to the Court of France.

Washington, D. C., Sept. 13, 1918. H. M. W. EDMONDS.

[1]From "Vie de M. Turgot" by J. A. M. C. Condorcet, London, 1787, p. 203.
[2]From MS. copy in the Library of Congress, Washington, D. C.

ADDITIONAL RESULTS OF EARTH-CURRENT OBSERVATIONS AT JERSEY, ENGLAND.

I am persuaded that the new facts which I have derived from the continued study of my observations of a subterranean electric current at Jersey, since I sent you the notes in January and February last,[1] will clear away more than one of the objections which may be raised either regarding the manner of capturing the earth-current without an aerial wire, or to the first and curious results which it has furnished.

The diurnal variation of two nearly equal oscillations which I obtained from my first observations is and should be of the same form as the diurnal variation in height of the water in a seaport open to the ocean tide. Twice in 24 hours the port is filled and emptied alternately, and these two oscillations of the sea are perceptibly equal in a given day. The variation of the potential observed at Jersey is a veritable *electric tide* which is produced in the Earth's crust parallel to the ocean tide at its surface.

What are the essential characteristics of an ocean tide? They are of two orders. Obeying the combined attractions of the Sun and the Moon, principally the Moon, on the Earth, the tide, from one day to another, presents a mean delay of 50 minutes, which nearly amounts to a delay of 24 hours in a period of 29 to 30 days. This is the length of a lunation. The potential of the Earth undergoes, under the influence of the Sun and the Moon in its diurnal variation, the same vicissitudes as the ocean. Each of its two daily maxima and minima is registered one day 50 minutes later than on the preceding day, so that in a lunar month of 29 to 30 days, each one of them has been registered once in every hour of the day and night. This plainly denotes an electric tide.

Another characteristic of the oscillations of the ocean tide is their amplitudes measured by the variation in the height of the water in a port between the low and high tides. When the attractions of the Moon and the Sun are added, as at the time of the new and the full Moon, the two bodies being then in conjunction or in opposition, the tides are greater. When the attractions counteract each other at the time of the first and last quarters, the action of the two celestial bodies being exerted at right angles, the tides are smaller. This second characteristic belongs also to the electric tide.

All this is shown in Table 1, where I have collected, in accordance with the six lunations studied from October 1917 to April 1918, the essential elements of this phenomenon.

If this is true, it will be objected, the diurnal variation of the earth-current is radically variable. How did it happen that in my previous note I said it was essentially fixed? The two statements are not contradictory. In my first note, I presented only the monthly and seasonal means which are really fixed as regards the position of the mean maxima

[1]See *Terr. Mag.*, vol. 23, pp. 37-39.

Table 1.—*Variations in the voltage of the earth-current at Jersey during 6 synodic revolutions of the Moon from October 27, 1917 to April 25, 1918 for each hour of G. M. T., expressed in ten-thousandths of a volt.*

G.M.T.	New Moon	•	First Quarter		Full Moon	.	Last Quarter		Mean Variation per Lunation	General variation in 1917
h										
0	+41	+37	− 9	+10	+52	+49	−14	−13	+19.1	+16.1
1	+18	+48	+14	−12	+34	+60	+ 3	−33	+16.5	+10.8
2	−11	+44	+38	−31	+ 3	+54	+18	−42	+ 9.1	+ 3.5
3	−38	+26	+43	−39	−25	+32	+27	−38	+ 1.0	− 5.2
4	−56	0	+40	−25	−47	0	+27	−23	−11.7	−13.8
5	−59	−28	+25	−21	−48	−27	+17	− 3	−18.0	−20.6
6	−47	−48	+ 3	− 1	−38	−48	+ 1	+17	−20.1	−24.0
7	−21	−56	−19	+20	−18	−54	−15	+31	−16.5	−22.8
8	+10	−49	−35	+36	+ 6	−45	−26	+36	− 8.4	−16.1
9	+40	−30	−42	+42	+28	−23	−27	+31	+ 2.4	− 5.2
10	+61	− 3	−39	+37	+44	+ 4	−21	+19	+12.7	+ 8.7
11	+66	+25	−26	+23	+51	+31	− 6	+ 3	+20.9	+20.2
Noon	+56	+47	− 8	+ 3	+47	+49	+ 9	−14	+23.6	+26.7
13	+32	+58	+11	−18	+34	+57	+22	−33	+20.4	+26.3
14	+ 1	+56	+27	−36	+ 8	+51	+29	−37	+12.4	+18.5
15	−29	+41	+37	−45	−20	+31	+30	−38	+ 0.9	+ 5.8
16	−51	+17	+38	−44	−47	+ 4	+24	−29	−11.0	− 6.8
17	−58	−10	+30	−33	−63	−27	+15	− 3	−18.6	−16.0
18	−50	−35	+14	−13	−64	−51	+ 3	+10	−23.3	−18.7
19	−29	−50	− 7	+10	−48	−64	−10	+30	−21.0	−14.5
20	− 1	−51	−26	+30	−17	−60	−21	+43	−12.9	− 5.8
21	+27	−38	−37	+42	+18	−41	−30	+45	− 1.8	+ 4.3
22	+46	−14	−39	+42	+47	−10	−32	+33	+ 9.1	+12.7
23	+51	+14	−29	+30	+61	+23	−26	+12	+17.0	+16.2
Mean Voltage	0.1068	0.1078	0.1025	0.1075	0.1075	0.1074	0.1066	0.1065	0.10658	0.08981

and minima. By about a day, the civil month and the lunation are the same (see the next to the last column of Table 1); the two maxima of the mean day will always fall at midnight and midday corresponding with the passages of the two bodies at the meridian, and the two minima at 6 h. and 18 h. corresponding with the two bodies at the horizon. This fixity of the phases of the mean diurnal variation of the current is further verified by the last column of the table where will be found the mean diural variation resulting from the 365 days of the year 1917.

It is necessary, moreover, to insist much on the explanation to be given to this mean fixity which I thought well to indicate in my previous communication. In the series of calm days in 1917, the greatest number has shown what I thought I might give as the normal variation of the earth-current; the others presented themselves with an opposite variation, maxima and minima having interchanged their hours of registration. The fact that the calm days as a whole, in each month of the year, always have the form of the mean diurnal variation of the whole lunation, shows

that the frequency of days of electric calm is greatest at the syzygies, epochs which impose on the mean lunation their common forms of variation that places the maxima of potential at midnight and midday and the minima at 6 h. and 18 h. On the other hand, since all opposition between the attracting forces should cease as soon as the resulting effect is a maximum or a minimum, the electric calms are again found at the epochs of the quadratures which are the epochs of the minima of resultant action. But at the quadratures, the maxima of potential arrive 6 hours later than at the syzygies. The variation should then be reversed, as is seen in our table in the 2 columns, "First Quarter" and "Last Quarter."

A final proof of the conformity of the two tides. It is known that the solar and lunar actions combined are strongest at the equinoxes and weakest at the solstices, causing the greatest and the smallest tides of the year.

The following is what has been observed, in this connection, at Jersey this year:

	Mean Amplitudes of the Tides		
	Electric Volts	Ocean m	Theoretical Coefficients
At the solstice (28, 29, 30 Dec. 1917) =	0.0093	8.66	84
At the equinox (13, 14, 16 Mar. 1918) =	0.0173	12.12	119

A satisfactory agreement; it is the same phenomenon under two different aspects. And yet the agreement is not absolute all along the line. There is one point, and a point that must be considered seriously, where there is disagreement. The ocean tide is later than the Moon, in the sense that the day of the new Moon the high sea does not coincide with the passage of our satellite at the meridian, but arrives a certain time afterwards, at Jersey 6 hours later. Now the electric tide is ahead of the Moon, the maximum of potential nearest the hour of the passage of the Moon at the meridian of Jersey being always in advance by one hour at the syzygies, and by 2 to 3 hours at the quadratures. This is the fact: it is a real discordance, which demands an explanation but which does not weaken in any degree the conclusion from what precedes. There is an electric tide just as there is on our globe an oceanic tide; the first like the second is immediately dependent upon the combined attractions of the Moon and Sun.

The phenomenon here under discussion is being further investigated.

Jersey, England, May, 1918. MARC DESCHEVRENS, S. J.

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HAZARD, D. L. Results of magnetic observations made by the United States Coast and Geodetic Survey in 1917. Washington, D. C., Dept. Comm., U. S. Coast Geod. Surv., Spec. Pub. No. 51, 1918 (64). 23 cm.

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INDIA, SURVEY OF. General report, 1914-15. From 1st October 1914 to 30th September 1915. Prepared under the direction of Colonel Sir S. G. Burrard, K. C. S. I., R. E., F. R. S., Surveyor General of India. Calcutta, 1916 (40 with 14 maps). 35½ cm. [On p. 22 is a brief report of the Magnetic Survey and the mean values of the magnetic elements at the various observatories for 1914.]

INDIA, SURVEY OF. General report, 1915-16. From 1st October 1915 to 30th September 1916. Prepared under the direction of Colonel Sir. S. G. Burrard, K. C. S. I., R. E., F. R. S., Surveyor General of India. Calcutta, 1917 (40 with 14 maps). 35½ cm. [On pp. 22-23 is a brief report of the Magnetic Survey and the mean values of the magnetic elements at the various observatories for 1915.]

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THE CLAIMS OF INTERNATIONAL SCIENCE.

The information given in the communication (page 143) by Dr. Edmonds is of peculiar interest during the present times. It would be worth while to know if any diplomat or militarist of the Central Powers was animated at any time by the spirit which prompted the issuance of the French and American measures for the safety of an expedition of an enemy country. A German magnetician strove to secure the continuance of the work of the pre-war German magnetic observatories, Tsingtau and Apia; whether he was equally successful with his own country as to the continuance of the work at the Belgian magnetic observatory at Uccle is not known. We do know, however, that the Japanese are continuing the work of the Tsingtau observatory, and that the work at the Apia observatory is being continued under the auspices of the New Zealand military authorities.

Let us hope that the day is not far distant when the world will be safe not only for democracy but also against interruptions in international scientific work by arbitrary acts!—*Ed.*

Terrestrial Magnetism

and

Atmospheric Electricity

VOLUME XXIII DECEMBER, 1918 NUMBER 4

RESULTS OF MAGNETIC OBSERVATIONS DURING THE SOLAR ECLIPSE OF JUNE 8, 1918, AT THE KAKIOKA MAGNETIC OBSERVATORY, JAPAN.

BY K. NAKAMURA, *Director, Central Meteorological Observatory.*

Fig. 1 is a full-size reproduction of the portion of the magnetogram obtained during the solar eclipse of June 8, 1918, at the Kakioka magnetic observatory, situated about 75 km. north-northeast of Tokyo. One mm. of ordinate corresponds to 1′.0 for declination (D), 5.3γ for horizontal intensity (H), and 6.2γ for vertical intensity (Z). The values of the base lines are : $D_0=$ 5°07′ W; $H_0=29790\gamma$; $Z_0=34900\gamma$. The time scale was such that 20 mm. equal one hour.

The five-minute values of the magnetic elements as scaled from the magnetograms for the period 19^h June 8 to 1^h June 9, 1918, Greenwich civil mean time, are contained in Table 1, where will be found also the corresponding values for June 7. The table contains furthermore the quantities, $\triangle D$, $\triangle H$, and $\triangle Z$, derived by subtracting the values of D, H and Z on June 7 from those on June 8, regarding here west declination as negative; a plus $\triangle D$, accordingly, signifies an eastward deflection of the declination needle.

The last three columns contain the differences, $\triangle X$, $\triangle Y$ and $\triangle I$, or the effects respectively, in the north component (+north), east component (+east) and inclination (+downward deflection).

[The circumstances of the eclipse at Kakioka were approximately as follows: Time of beginning, 19^h 46^m; middle, 20^h 41^m; ending, 21^h 42^m, Greenwich civil mean time, June 8; magnitude of maximum obscuration, 0.88.—*Ed.*]

TABLE 1.—*Magnetic elements observed at Kakioka, Japan, June 7 and 8, 1918.*

G.M.T.	D = West 5°+			H = 29700γ+			Z = 34750γ+			ΔX	ΔY	ΔI
	June 7	June 8	ΔD	June 7	June 8	ΔH	June 7	June 8	ΔZ			
h m	′	′	′	γ	γ	γ	γ	γ	γ	γ	γ	′
19 00	20.9	20 7	+0.2	13.8	20.2	+6 4	67.9	58.0	—9.9	+6.5	+1.1	—0.85
05	20.8	20.5	+0.3	14.3	20.2	+5.9	68.5	58.0	—10.5	+6.1	+2.0	—0.85
10	20.7	20.4	+0 3	14.8	20.7	+5.9	69.2	58.6	—10.6	+6.1	+2.0	—0.85
15	20.6	20.3	+0.3	14.8	21.2	+6.4	69.2	58.6	—10.6	+6.6	+2.0	—0.88
20	20.5	20.2	+0.3	14.8	21.2	+6.4	69.2	58.6	—10.6	+6.6	+2.0	—0.88
25	20.4	20.1	+0.3	13.8	21.8	+8.0	69 2	59.2	—10.0	+8.2	+1.8	—0.95
30	20.3	20.0	+0.3	13.8	21.2	+7.4	69.2	59.2	—10.0	+7.6	+1.9	—0.91
35	20.2	19.9	+0.3	13.8	21.8	+8.0	69.2	58.6	—10.6	+8.2	+1.8	—0.98
40	20.1	20.0	+0 1	13.8	21.8	+8.0	69.2	58.6	—10.6	+8.0	+0.1	—0.98
45	20.0	20.1	—0 1	14.3	23.4	+9.1	68.5	59.2	—9.3	+9.0	—1.7	—0.97
50	19.9	20.0	—0.1	14.8	23.9	+9.1	68.5	59.9	—8.6	+9.0	—1.7	—0.94
55	19.8	20.0	—0 2	14.8	25.0	+10.2	68.5	59.9	—8.6	+10.0	—2.7	—1.00
20 00	19.7	20.0	—0.3	14.8	24.4	+9.6	67.9	59.2	—8.7	+9.3	—3.5	—0.97
05	19.7	20.1	—0.4	14.8	24.4	+9 6	67.3	59.2	—8.1	+9.2	—4.3	—0.94
10	19.6	20.1	—0.5	15.4	24.4	+9.0	67.3	59.2	—8.1	+8.6	—5.1	—0.91
15	19.5	20.0	—0.5	15.4	23.9	+8 5	67.3	58.6	—8.7	+8.1	—5.1	—0.88
20	19.4	19.8	—0.4	15.4	22.3	+6.9	66.7	57.4	—9.3	+6.6	—4.1	—0.85
25	19.3	19.5	—0.2	14.8	20.7	+5.9	66.1	56.2	—9.9	+5.7	—2.3	—0.82
30	19.2	19.3	—0.1	14.8	19.6	+4.8	65.5	54.9	—10.6	+4.7	—1.3	—0.79
35	19.1	19.1	0.0	14.8	18.0	+3.2	65.5	53.7	—11.8	+3.2	—0.3	—0.76
40	19.1	19.0	+0.1	14.8	17.5	+2.7	65.5	53.1	—12.4	+2.8	+0.6	—0.76
45	19.0	18.9	+0.1	14.8	18.0	+3.2	65.5	52.4	—13.1	+3.3	+0.6	—0.82
50	18.9	19.0	—0.1	14.3	19.6	+5.3	65.5	52.4	—13.1	+5.2	—1.4	—0.94
55	18.8	18.9	—0.1	13.8	21.2	+7.4	64.8	54.3	—10.5	+7.3	—1.6	—0.94
21 00	18.8	19.0	—0.2	12.7	21.8	+9.1	64.8	54.3	—10.5	+8.9	—2.6	—1.03
05	18.8	19.0	—0.2	12.2	22.3	+10.1	64.2	54.9	—9.3	+9.9	—2.7	—1.03
10	18.9	19.0	—0.1	11.6	20.2	+8.6	63.6	53.7	—9.9	+8.5	—1.7	—0.98
15	19.0	18.9	+0.1	11.1	19.1	+8.0	63.0	53.1	—9.9	+8.0	+0.1	—0.94
20	19.1	18.6	+0.5	10.0	17.5	+7.5	62.4	51.8	—10.6	+7.9	+3.6	—0.95
25	19.1	18.4	+0.7	9.5	16.4	+6.9	61.7	50.6	—11 1	+7.4	+5.4	—0.94
30	18.9	18.5	+0.4	9.5	15.9	+6.4	61.1	50.0	—11.1	+6.7	+2.8	—0.91
35	18.9	18.4	+0.5	9.5	15.4	+5.9	60.5	49.4	—11.1	+6.3	+3.8	—0.88
40	18.8	18.3	+0.5	8.4	15.4	+7.0	59.3	48.8	—10.5	+7.4	+3.8	—0.91
45	18.8	18.2	+0.6	7.9	14.3	+6.4	58.0	48.2	—9.8	+6.8	+4.6	—0.84
50	18.9	18.2	+0.7	7.4	13.8	+6.4	57.4	46.3	—11.1	+6.9	+5.4	—0.91
55	18.9	18.0	+0.9	7.4	13.8	+6.4	56.8	45.7	—11.1	+7.1	+7.2	—0.91
22 00	18.9	18.1	+0.8	6.8	14.3	+7.5	56.2	45.7	—10.5	+8.1	+6.2	—0.94
05	18.9	18.3	+0.6	6.3	13.8	+7.5	55.6	45.7	—9.9	+8.0	+4.5	—0.91
10	19.0	18.5	+0.5	6.3	13.8	+7.5	55.6	45.7	—9.9	+7.9	+3.6	—0.91
15	19.0	18.6	+0.4	5.8	13.2	+7.4	55.6	45.1	—10.5	+7.7	+2.8	—0.94
20	19.1	18.7	+0.4	6.3	12.2	+5.9	55.6	44.5	—11.1	+6.2	+2.9	—0.88
25	19.1	18.8	+0.3	6.8	10.6	+3.8	55.6	42.7	—12.9	+4.0	+2.2	—0.84
30	19.1	18.7	+0.4	7.4	10 0	+2.6	55.6	42.1	—13.5	+2.9	+3.2	—0.81
35	19.1	18.7	+0.4	7.9	10.0	+2.1	56.2	41.4	—14.8	+2.4	+3.2	—0.84
40	19.1	18.7	+0.4	9.0	9.5	+0.5	56.8	40.8	—16.0	+0.8	+3.4	—0.81
45	19.0	18.7	+0.3	9.0	9.0	0.0	56.8	40.2	—16.6	+0.2	+2.6	—0.81
50	19.0	18.8	+0.2	9.5	9.0	—0.5	56.8	39.6	—17.2	—0.3	+1.8	—0.81
55	19.1	19.0	+0.1	10.0	8.4	—1.6	56.8	40.2	—16.6	—1.5	+1.0	—0.72
23 00	19.2	19.2	0.0	10.0	8.4	—1.6	56.8	40.2	—16.6	—1.6	+0.2	—0.72
05	19.2	19.3	—0.1	10.0	8.4	—1 6	56.2	40.8	—15.4	—1.7	—0.7	—0.66
10	19.3	19.4	—0.1	10.0	9.0	—1.0	56.2	40.8	—15.4	—1.1	—0.8	—0.69
15	19.2	19.6	—0.4	10.6	9.0	—1.6	56.2	40.8	—15.4	—1.9	—3.3	—0.66
20	19.2	19.8	—0.6	11.6	9.0	—2.6	56.8	41.4	—15.4	—3.1	—4.9	—0.61
25	19.2	19.9	—0.7	12.2	9.0	—3.2	56.2	41.4	—14.8	—3.8	—5.7	—0.54
30	19.4	19.8	—0.4	12.2	9.0	—3.2	56.2	42.1	—14.1	—3.5	—3.1	—0.51
35	19.5	19.8	—0.3	12.7	9.5	—3.2	56.8	42.7	—14.1	—3.4	—2.3	—0.51
40	19.4	19.9	—0.5	13.2	9.0	—4.2	56.8	43.3	—13.5	—4.6	—3.9	—0.42
45	19.2	20.0	—0.8	13.8	8.4	—5.4	56.8	43.9	—12.9	—6.0	—6.4	—0.32
50	19.0	20.2	—1.2	13.8	7.4	—6.4	56.2	43.9	—12.3	—7.3	—9.7	—0.23
55	19.1	20.4	—1.3	12.7	6.3	—6.4	55.6	44.5	—11.1	—7.4	—10.6	—0.18
24 00	19.4	20.6	—1.2	11.6	5.8	—5.8	55 0	44.5	—10.5	—6.7	—9.8	—0.18
05	19.7	20.6	—0.9	9.0	5.2	—3.8	53.7	42.7	—11.0	—4.5	—7.4	—0.32
10	20.0	20.7	—0.7	9.5	5.2	—4 3	54.4	40.8	—13.6	—4.8	—5.6	—0.42
15	20.5	20.8	—0.3	9.0	5.2	—3.8	55.0	40.8	—14.2	—4.0	—2.2	—0.48
20	20.8	20.8	0.0	8.4	5.8	—2.6	55.6	40.2	—15.4	—2.6	+0.2	—0.61
25	20.9	20.9	0.0	8.4	5.8	—2.6	56.2	40.2	—16.0	—2.6	+0.2	—0.63
30	21.0	21.0	0.0	8.4	5.8	—2.6	56.8	39.6	—17.2	—2.6	+0.2	—0.69
35	21.1	21.1	0.0	9.0	5.8	—3.2	57.4	39.0	—18.4	—3.2	+0.3	—0.72
40	21.1	21.2	—0.1	9.5	5.8	—3.7	58.0	38.3	—19.7	—3.8	—0.5	—0.75
45	21.1	21.4	—0.3	10.0	6.8	—3.2	58.7	38.3	—20.4	—3.4	—2.3	—0.81
50	21.2	21.5	—0.3	10.6	7.4	—3.2	59.3	39.0	—20.3	—3.4	—2.3	—0.81
55	21.3	21.5	—0.2	10.6	7.9	—2.7	59.3	39.0	—20.3	—2.8	—1.5	—0.83
25 00	21.3	21.5	—0.2	10.6	9.0	—1.6	59.3	39.0	—20.3	—1.8	—1.6	—0.90

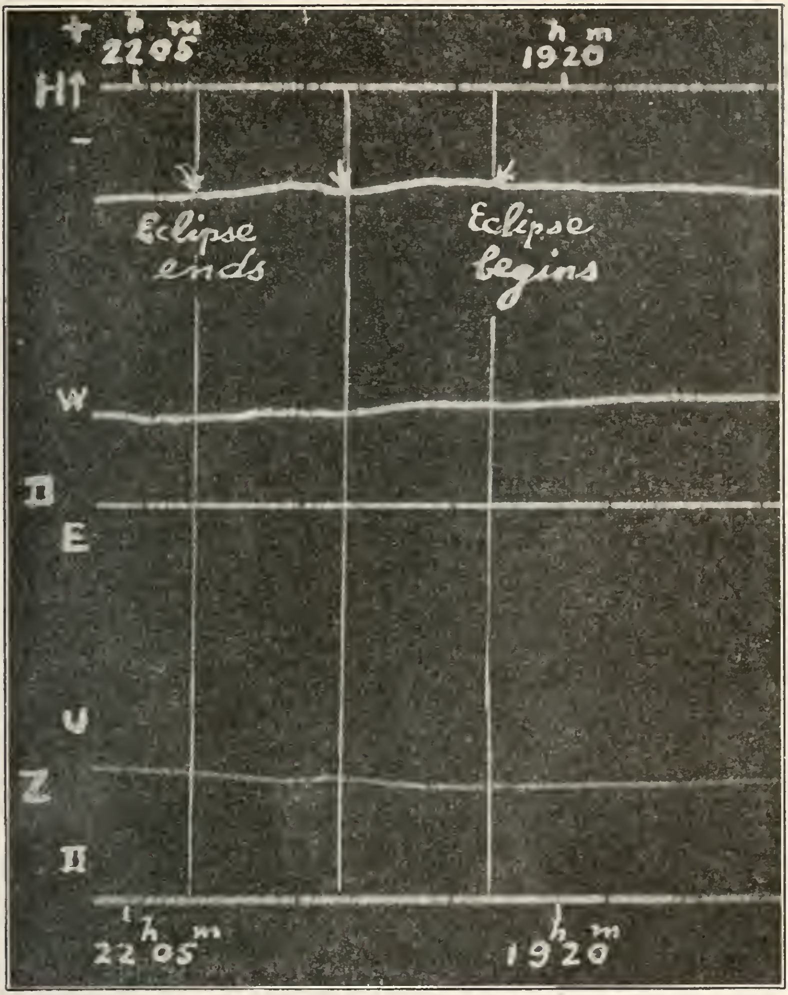

FIG. 1.—Kakioka Magnetogram, June 8, 1918. (Full size; see p. 164.)

RESULTS OF MAGNETIC OBSERVATIONS DURING THE SOLAR ECLIPSE OF JUNE 8, 1918, AT AGINCOURT AND MEANOOK, CANADA.—*Concluded.*

By R. F. STUPART.

Table 9 contains the results of the scalings from the *D*-magnetograms obtained at the Meanook magnetic observatory at 5-minute intervals for the period June 8, 18^h to June 9, 2^h, G. M. T. Each value is the mean for the 5-minute space, beginning 2.5 minutes before the tabulated time.

It will not be possible to supply the *H*- and *Z*-values for Meanook as this station is not yet equipped with self-recording magnetometers, other than the declinometer.

Table 10 gives the mean hourly values of the magnetic elements at Agincourt and Meanook for five selected quiet days during June 1918 and for all days.

Our characterization of June 7, 1918, G. M. T., from the two observatories, is "character 1."

TABLE 9.—*Five-minute means of declinations at Meanook, June 8, 1918, from scalings of magnetogram at 5-minute intervals (mean of a 5-minute space.)* [$D=27°$ 30′ E.+tabular value.]

G.M.T.	June 8						June 9		
	18^h	19^h	20^h	21^h	22^h	23^h	0^h	1^h	2^h
m	′	′	′	′	′	′	′	′	′
0	17.0	11.5	8.0	7.5	5.7	8.5	9.8	9.8	10.6
5	16.7	11.2	8.7	8.7	6.2	8.7	10.1	9.6	...
10	17.2	10.2	8.8	7.8	6.6	8.7	10.6	9.4	...
15	15.9	10.1	8.8	7.3	7.3	8.8	10.9	9.5	...
20	16.1	8.9	7.8	6.3	7.4	8.9	10.3	9.8	...
25	14.8	8.7	6.2	5.6	7.7	9.2	10.1	10.1	...
30	14.7	8.3	5.0	5.5	7.8	9.1	10.2	10.2	...
35	14.1	7.0	5.6	5.6	8.4	8.8	10.2	10.5	...
40	13.7	7.0	5.9	4.8	8.7	8.7	10.3	10.3	...
45	13.3	6.9	5.9	3.7	8.5	8.8	10.5	10.3	...
50	13.0	7.0	5.9	4.1	8.4	8.8	10.1	10.2	...
55	12.4	7.7	6.2	4.5	8.3	9.4	9.8	10.3	...

TABLE 10.—*Mean hourly values of the magnetic elements for 5 select quiet days and for all days at Agincourt and Meanook, Canada.*

	Agincourt						Meanook		
75th M.T.	Declination (*D*)		Hor. Int. (*H*)		Ver. Int. (*Z*)		105th M.T.	Declination (*D*)	
	5 days	All days	5 days	All days	5 days	All days		5 days	All days
	—6°37′.7+	—6°37′.8+	15937.1γ+	15929.3γ+	58359.8γ+	58360.3γ+		27° 43′.3+	27° 44′.2+
h	′	′	γ	γ	γ	γ	h	′	′
1	+0.2	0.0	—0.1	+0.8	+0.1	—6.9	1	—1.3	—2.1
2	+0.4	+1.0	+1.4	+1.6	—0.1	—7.4	2	—1.7	—1.3
3	+0.8	—0.5	+0.8	—3.4	—0.1	—12.2	3	—1.2	—0.1
4	+1.7	+0.2	+2.4	—2.1	+0.4	—9.8	4	+0.7	+2.9
5	+3.2	+2.7	+3.0	—7.9	+1.3	—5.6	5	+3.0	+6.9
6	+5.2	+5.2	+4.1	—1.4	+0.8	—5.9	6	+5.2	+7.5
7	+7.9	+6.8	+1.5	—10.3	+0.7	—2.7	7	+8.6	+10.5
8	+7.9	+6.5	—4.8	—17.5	—0.2	—4.5	8	+10.0	+10.1
9	+6.3	+4.6	—13.6	—21.8	+0.7	—1.4	9	+9.9	+8.7
10	+2.6	+2.1	—22.7	—29.6	—3.9	—1.4	10	+7.3	+7.1
11	—2.8	—2.4	—23.4	—24.0	—5.3	—1.7	11	+3.6	+3.3
12	—6.5	—5.4	—11.3	—13.1	—6.0	—2.4	12	—0.4	—1.1
13	—7.3	—6.4	—5.6	+1.6	—3.7	+0.5	13	—3.3	—4.8
14	—7.1	—6.4	+3.6	+12.6	—3.0	+3.8	14	—6.0	—5.8
15	—5.2	—5.0	+10.6	+20.7	+0.7	+8.5	15	—5.8	—6.2
16	—3.3	—3.2	+14.1	+26.8	+3.0	+10.8	16	—6.2	—6.4
17	—1.7	—1.0	+11.5	+29.0	+3.8	+11.8	17	—4.5	—6.1
18	—0.5	—0.5	+9.0	+18.7	+2.7	+11.6	18	—3.2	—5.4
19	+0.2	+0.6	+5.6	+11.5	+3.3	+13.2	19	—2.2	—4.3
20	—0.2	—0.1	+4.6	+6.3	+2.1	+9.7	20	—2.2	—2.8
21	—0.5	+1.0	+3.3	+4.5	+1.4	+4.4	21	—2.1	—4.7
22	—0.8	0.0	+3.2	+2.3	+0.7	+0.1	22	—2.5	—2.6
23	—0.1	+0.1	0.0	—3.9	+0.2	—4.6	23	—2.4	—1.9
24	—0.2	+0.1	+3.4	—1.6	+0.7	—8.5	24	—2.0	—1.4

Remark.—The values at the head of the columns are the means of the 5 select days and of all days, respectively; the selected days are June 1, 4, 23, 25 and 30, G.M.T.

RESULTS OF MAGNETIC AND ELECTRIC OBSERVATIONS MADE DURING THE SOLAR ECLIPSE OF JUNE 8, 1918.—*Continued.*

By L. A. Bauer, H. W. Fisk, and S. J. Mauchly.

Part I.—MAGNETIC OBSERVATIONS.—*Continued.*

26. The effects are especially noticeable at stations where the normal diurnal variation of the Earth's magnetism at the time was large—for example, near the morning or afternoon elongations of the declination-needle. Kakioka, Japan, was somewhat favorably situated as far as the morning elongation was concerned, and Sitka with regard to the afternoon elongation. At

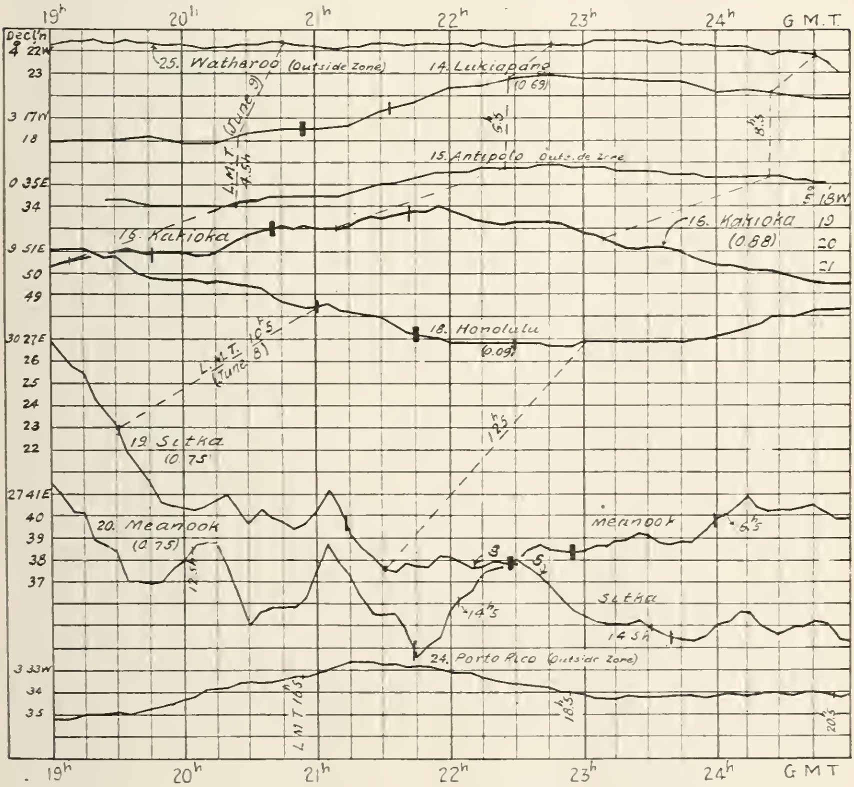

Fig. 8.—Declination Curves, June 8, 1918.—*Continued.*

the stations in the United States the eclipse occurred generally in the late afternoon hours when the normal diurnal declination-changes were themselves small. At Goldendale, the most western station in the United States, the eclipse began just after the time when the afternoon elongation would have ordinarily occurred; the local mean time of totality was $2^h\ 57^m$ P. M., hence when the course of the diurnal variation of declination had already been reversed and the amount reduced to less than that at the afternoon elongation.

27. Kakioka, Sitka, Meanook and Goldendale (Figs. 7 and 8) appear to disclose effects such as we might expect from the previous results of the systematic eclipse observations beginning with the one of May 28, 1900. At the United States stations east of Goldendale, as the eclipse occurred late in the afternoon, the eclipse effects in declination, in view of the ever-present minor fluctuations of the Earth's magnetism, are not always at once evident from Fig. 7 but they are found disclosed in Fig. 9. The results of the solar eclipse of June 8, 1918 are in every respect similar to those for the one of August 21, 1914. At the European stations where the eclipse occurred during the time of day when the diurnal march of the declination-needle was rapid and comparatively large, a distinct trough, or bay, of a small wave revealed itself, the Greenwich mean time of this bay occurring distinctly later where the eclipse (maximum obscuration) took place later. (See Fig. 4, *Terr. Mag.* vol. 21, 1916, p. 83.) As the eclipse of August 21, 1914 advanced towards the easterly stations, where the time of totality, or of maximum obscuration, occurred in the later afternoon hours, a declination-effect to be referred to the eclipse was not immediately discernible, though when the curve was compared with a mean curve, obtained from undisturbed days before and after the eclipse, there was an indication of an effect of the to-be-expected kind. Such a case, for example, was Ekaterinburg, Russia, where the local mean time of maximum obscuration was $4^h\ 49^m$ P. M. (See *Terr. Mag.* vol. 21, 1916, p. 85, second paragraph.)

28. Since the curves (Fig. 4, *Terr. Mag.* vol. 21, p. 83) for the eclipse of August 21, 1914 were plotted so that an upward movement meant a deflection of the declination-needle to the west, instead of to the east, as is the case for the curves of the eclipse of June 8, 1918 (Figs. 7 and 8), the troughs (bays) of the former correspond to the crests of the latter. Thus looking at the three upper curves (Sitka, Meanook and Goldendale, Fig. 7), we have seemingly

a crest (instead of a trough as for August 21, 1914) just before the time of maximum obscuration. The wave which appeared at the time of the eclipse at these stations is shown more clearly in Fig. 9, obtained by subtracting from the observed declinations on June 8 those resulting from the mean of undisturbed values on previous and subsequent days.

29. The next features of no little interest are the preliminary waves between about 20^h and 22^h Greenwich civil mean time June 8, which reveal themselves, in greater or less degree, at all stations on the North American continent. They are found reduced at Honolulu, near the southern boundary of the region of visibility, the magnitude of maximum obscuration being here but 0.09. Though the prominent crest, shortly after 21^h, occurs at nearly the same absolute time over the region of visibility of the eclipse, so that one might conclude that it is a cosmic effect, it does not appear so prominent at the stations outside the region (see Watheroo and Antipolo of Figs. 8 and 9). The effects at the Porto Rico station, situated just east of the region of visibility, are found altered in character, the preliminary troughs having almost disappeared and the curve rising to a single crest at about $21^h\ 15^m$ G. M. T.; a belated trough occurs between 23^h and 24^h (see Fig. 9).

30. The characteristics of the various waves differ from station to station (see Fig. 9) not only according to the local mean times at which they may occur at the different stations, and to the eclipse-circumstances, but also markedly according to the local conditions, possibly the meteorological conditions. The average period, from trough to trough, or from crest to crest, is about $1^h.5$, or almost the local eclipse-period, from beginning to end. The waves are strikingly developed at L. A. Bauer's station, Corona, the altitude of which above sea-level was about 11,800 feet. The ranges of the waves at the stations Green River, Lake Moraine and Lakin (Fig. 9), situated about in the same region, are not as large as at Corona.

A more complete discussion of the declination-effects is given later.

31. Table 5 contains the *geographic positions, approximate magnetic elements and eclipse-circumstances for each station.* The column-headings will be readily understood; "G. M. T." stands for Greenwich civil mean time, "L. M. T." for local mean time, "Mag." for magnitude of obscuration or fraction of the Sun's

diameter covered at maximum eclipse, and "Tot." for period in seconds of duration of total eclipse. All stations in Group I were in the belt of totality; at No. 7 (Orlando), the end of the eclipse occurred after sunset (a. s. s.).

TABLE 5.—*Geographic positions, magnetic elements and eclipse-circumstances.*

No.	Group	Station	Geographic Position			Approx. Magnetic Elements			Approximate G. M. T.			Maximum Obscuration		
			Lat.	Longitude		D	H	Z	Beg.	Mid.	End	L.M.T.	Mag.	Tot.
			° ′	° ′	h m	°	cgs	cgs	h m	h m	h m	h m		s
1	I	Goldendale	45 50 N	120 50 W	—8 03	23.3 E	.201	+.538	21 41	23 00	24 12	14 57	1.01	117
2	I	Green River	41 32 N	109 28 W	—7 18	17.3 E	.213	+.544	22 04	23 18	24 24	16 00	1.01	99
3	I	Corona	39 57 N	105 42 W	—7 03	15.7 E	.222	+.536	22 11	23 23	24 27	16 20	1.01	92
4	I	Lakin	37 53 N	101 18 W	—6 45	12.5 E	.227	+.535	22 18	23 28	24 30	16 43	1.01	84
5	I	Mena	34 35 N	94 14 W	—6 17	8.0 E	.243	+.519	22 34	23 35	24 34	17 18	1.01	70
6	I	Brewton	31 07 N	87 04 W	—5 48	4.3 E	.252	+.490	22 38	23 40	24 36	17 52	1.01	59
7	I	Orlando	28 33 N	81 21 W	—5 25	0.9 E	.264	+.469	22 43	23 42	a.s.s.	18 17	1.01	48
8	II	Berkeley	37 51 N	122 16 W	—8 09	18.3 E	.250	+.470	21 49	23 10	24 22	15 01	0.79	....
9	II	Lake Moraine	38 49 N	105 00 W	—7 00	15.0 E	.223	+.528	22 14	23 25	24 28	16 25	0.99	....
9a	II	Urbana	40 06 N	88 14 W	—5 53	3.2 E	.194	+.566	22 26	23 28	24 25	17 35	0.83	....
9b	II	Columbia	38 56 N	92 20 W	—6 09	6.5 E	.211	+.561	22 25	23 29	23 28	17 20	0.89	....
10	II	Austin	30 20 N	97 24 W	—6 30	9.2 E	.269	+.468	22 34	23 40	24 39	17 10	0.87	....
11	II	Washington	38 58 N	77 04 W	—5 08	4.7 W	.188	+.549	22 33	23 29	24 21	18 21	0.74	....
12	II	Woburn	42 30 N	71 08 W	—4 45	13.5 W	.170	+.556	22 31	23 23	24 12	18 38	0.63	....
13	II	Rivière du Loup	47 52 N	69 34 W	—4 38	21.4 W	.140	+.583	22 29	23 16	24 03	18 38	0.52	....
14	III	Lukiapang[1]	31 19 N	238 58 W	—15 56	3.3 W	.332	+.338	.....	20 54	21 34	4 58	0.69	....
15	III	Antipolo	14 36 N	238 50 W	—15 55	0.6 E	.381	+.111	out-	side	zone	....	......	....
16	III	Kakioka	36 14 N	219 49 W	—14 39	5.4 E	.297	+.348	19 46	20 41	21 42	6 02	0.88	....
17	III	Apia	13 48 S	171 46 W	—11 27	10.0 E	.354	—.203	out-	side	zone	....	......	....
18	III	Honolulu	21 19 N	158 04 W	—10 32	9.8 E	.289	+.239	21 01	21 45	22 30	11 13	0.09	....
19	III	Sitka	57 03 N	135 20 W	—9 01	30.4 E	.156	+.559	21 13	22 27	23 40	13 26	0.75	....
20	III	Meanook	54 37 N	113 20 W	—7 33	27.7 E	.129	+.605	21 44	22 54	23 59	15 18	0.75	....
21	III	Tucson	32 15 N	110 50 W	—7 23	13.8 E	.270	+.457	22 15	23 30	24 34	16 07	0.76	....
22	III	Agincourt	43 47 N	79 16 W	—5 17	6.6 W	.159	+.585	22 27	23 23	24 15	18 01	0.68	....
23	III	Cheltenham	38 44 N	76 50 W	—5 07	6.2 W	.192	+.555	22 33	23 29	24 21	18 22	0.74	....
24	III	Porto Rico	18 09 N	65 26 W	—4 22	3.6 W	.28[illegible]	+.348	out-	side	zone	....	......	....
25	III	Watheroo	30 19 S	244 07 W	—16 16	4.4 W	.251	—.508	out-	side	zone	....	......	....

ADDITIONAL DECLINATION DATA.

32. *Watheroo, West Australia.* Table 6 contains the five-minute means of the magnetic declinations observed every minute by eye-readings with magnetometer, C. I. W. No. 18, during the prescribed interval, at the site of the Watheroo magnetic observatory. This observatory is being established by the Department of Terrestrial Magnetism under the superintendence of W. F. Wallis, observer-in-charge. Watheroo was outside the region of visibility, the observation-interval occurring from 2^h 44^m to 8^h 44^m A. M., local mean time June 9, 1918, or from 19^h June 8 to June 9, 1^h, Greenwich civil mean time. The value of one division of the magnetometer scale was 1′.95. The observer was W. C. Parkinson.

[1]The maximum phase of the eclipse occurred at Lukiapang at sunrise, the G. M. T. for which (lower limb) was 20^h 54^m June 8, 4^h 58^m local mean time, June 9.

TABLE 6.—*Five-minute means of declination observations at Watheroo during the solar eclipse of June 8, 1918.*
[$D = 4° 20'$ W. + tabular value.]

G.M.T.	19ʰ	20ʰ	21ʰ	22ʰ	23ʰ	24ʰ	25ʰ	G.M.T.	19ʰ	20ʰ	21ʰ	22ʰ	23ʰ	24ʰ
m	′	′	′	′	′	′	′	m	′	′	′	′	′	′
0	1.72	1.70	1.83	1.60	1.58	1.75	2.95	30	1.60	1.73	1.65	1.67	1.43	2.08
5	1.58	1.80	1.90	1.60	1.42	1.80	2.98	35	1.42	1.70	1.65	1.68	1.58	2.00
10	1.47	1.90	1.90	1.67	1.35	1.80	....	40	1.58	1.50	1.70	1.70	1.45	2.07
15	1.50	1.80	1.75	1.60	1.40	1.85	....	45	1.62	1.45	1.60	1.70	1.62	2.22
20	1.42	1.80	1.77	1.70	1.45	2.03	....	50	1.72	1.58	1.60	1.68	1.63	2.48
25	1.62	1.72	1.65	1.80	1.40	2.25	....	55	1.72	1.68	1.60	1.68	1.65	2.98

33. *Columbia, Missouri.* The following explanatory remarks are extracted from Prof. H. B. Wahlin's report:

The declination readings were taken inside a tent every minute from 20ʰ June 8 to 2ʰ June 9, Greenwich civil mean time, and the temperature was read every fifth minute. The variometer used consisted of a bell-shaped magnet with mirror attached, suspended by a silk fiber. The deflections of the magnet were read by means of a telescope and scale to the nearest 0.1 mm. As the distance between mirror and scale was 153.2 cm., one mm. of scale corresponded to an angular deflection of magnet of 1′.12. All magnetic material, with the exception of two small pieces of iron about 3x7 cm. in the roof of the tent, was removed. The instruments were shielded as far as possible from air currents. Experiments were made to determine the correction in the reading due to the torsion in the fiber and it was found that this correction was less than 1 per cent.

An approximate value of the base line was deduced from previous observations of the Coast and Geodetic Survey at this station, viz., 6° 27′ east. Table 7 contains the five-minute means of the resulting declination values.

TABLE 7.—*Five-minute means of declination observations at Columbia, Missouri, during the solar eclipse, June 8, 1918.*
[$D = 6° 20'$ E. + tabular value.]

G.M.T.	20ʰ	21ʰ	22ʰ	23ʰ	24ʰ	25ʰ	26ʰ
m	′	′	′	′	′	′	′
0	7.0	6.9	6.8	8.5	9.6	8.2	6.6
5	7.0	7.3	7.1	8.5	9.8	7.9	...
10	7.3	7.4	7.4	8.7	9.9	7.7	...
15	7.2	7.3	7.6	8.9	9.9	7.5	...
20	7.3	6.8	7.4	8.9	10.0	7.5	...
25	7.1	7.1	7.4	9.1	10.0	7.4	...
30	7.0	7.1	7.7	9.3	9.9	7.3	...
35	6.5	7.2	8.3	9.3	9.7	7.2	...
40	6.8	7.3	8.1	9.2	9.6	7.1	...
45	6.4	7.0	8.4	9.4	9.2	6.9	...
50	6.5	7.2	8.4	9.5	8.7	6.9	...
55	6.8	6 6	8.4	9.6	8.5	6.7	...

34. *Urbana, Illinois.* Variations of the magnetic declination were observed by Prof. C. T. Knipp at the Coast and Geodetic Survey station in Roselawn Cemetery, south of the University of Illinois. The following notes are taken from Prof. Knipp's report:

The station is situated about 600 feet south of some private greenhouses and 2/5 mile east of the Illinois Central Railroad. There are farm buildings and large silos ½ mile to the south by west while the stock-judging pavilion (of iron and concrete) is 2/5 mile to the northeast and the University Armory (of massive iron framework) is located 2/5 mile due north. The university power house is situated 1¼ miles north by east and a street-car line runs about 1 mile to the north.

The variometer used consisted of a magnet about 6x3x0.5 mm., mounted in an aluminum strip carrying a 0.5 inch mirror suspended by a single silk fiber about 10.5 cm. long. The magnet was housed in a brass cup, covered by a glass window made securely airtight. A light mica vane was attached to the moving system, the clearance being close. One mm. of the scale corresponded to an angular deflection of the magnet of 1′.82.

The variometer with the accessory lamp and scale was mounted on a slab of blackboard slate supported by four wooden posts driven into the ground over the station mark. This apparatus was covered by a 9x9 foot tent. Every precaution was taken to remove magnetic substances. The electric illuminating circuit, furnished by a 6-volt lamp and storage battery, was tested and adjusted so as to have zero effect. A Studebaker 6-cylinder automobile when moved from a position 30 ft. to 300 ft. changed the deflection by 1.5 mm. with the scale distance of 94.2 cm. An occasional automobile passed on the three sides of the cemetery, distant about 500 ft., without having a marked effect on the needle.

The apparatus was set up Saturday morning, June 8. Circumstances prevented the beginning of consecutive readings until 21^h 45^m Greenwich civil mean time June 8.

The correction on Greenwich mean time of the chronometer used, was furnished by the astronomical department of the University of Illinois, as was also the chronometer.

The approximate value of the base line as determined from previous observations of the Coast and Geodetic Survey was 3° 13′ East. The five-minute values of the resulting observations are given in Table 8.

TABLE 8.—*Five-minute means of declination observations at Urbana, Illinois, during the solar eclipse, June 8, 1918.*

[D = 3° E. + tabular value.]

G.M.T.	21^h	22^h	23^h	24^h	G.M.T.	21^h	22^h	23^h	24^h
m		′	′	′	m	′	′	′	′
0	....	7.7	12.3	13.7	30	....	9.4	12.9	14.4
5	....	8.2	12.8	14.1	35	....	9.7	13.3	14.3
10	....	8.3	12.4	14.2	40	....	10.1	13.2	14.0
15	....	8.8	12.8	14.0	45	7.5	10.6	13.1	13.9
20	....	8.6	12.4	14.0	50	7.2	11.6	13.3	13.9
25	....	9.4	13.0	14.5	55	7.2	12.0	13.1	13.3

Final Discussion of Declination Effects.

35. The magnetic data having now been completely reduced for all the contributing stations, we may pass to the final discussion of the declination effects with the aid of the differential quantities, $\triangle D$, given in Table 9 for 26 stations; of these stations 7 were in the belt of totality, 23 in the region of visibility of the eclipse, and 3 were just outside the region of visibility. The quantities for the various stations will be found plotted in Fig. 9; the same explanations given for Figs. 7 and 8, (see paragraph 24) apply to Fig. 9. The $\triangle D$'s were obtained by subtracting from the observed declinations on June 8 those observed at corresponding times on some normal or undisturbed day, or days; they are affected, of course, by any constant or variable difference in D between that of the mean normal day and that for June 8 had there been no eclipse.

At the stations numbers 3, 4, 5, 6, 8, 12, and 16, the normal day was taken as June 7 on which declination-data corresponding to those on June 8 had been obtained. Judging from information received, June 7, while not a magnetically-quiet day entirely, was but little disturbed. June 9 and 10, on the other hand, were disturbed, at times considerably, and so the corresponding declination readings obtained at some of the stations on those days could not be utilized. From the 5 observatories of the United States Coast and Geodetic Survey, stations Nos. 18, 19, 21, 23 and 24, the normal values were based upon the data for 10 magnetically-quiet days in June, these days being June 1, 2, 3, 4, 23, 24, 25, 28, 29 and 30 (see Table 12, *Terr. Mag.*, vol. 23, p. 119). In the case of the 2 observatories of the Canadian Meteorological Service, stations Nos. 20 and 22, the normal values depend on the 5 magnetically-quiet days, June 1, 4, 23, 25 and 30 (see Table 10, *Terr. Mag.*, vol. 23, p. 154). For the remainder of the stations, Nos. 1, 2, 7, 9, 9a, 9b, 10, 11, 13, 14, 15, and 25, it was necessary to deduce normal values from those at contiguous stations, or as in the case of Nos. 14 and 15, from observatory tables of undisturbed diurnal variations, for previous years; in view of there being some uncertainty in the $\triangle D$'s thus derived, the curves in Fig. 9 for these stations are broken. For No. 1 (Goldendale) some declinations observed on June 7 were also available; when this was the case the $\triangle D$-curve is drawn in full. $A + \triangle D$ means a deflection of the declination-needle toward the east, which is shown by an upward movement of the curve.

TABLE 9.—*Declination effects, or values of Δ D, June 8, 1918.*

G.M.T.	Group I (Totality Stations)							Group II (Field Stations Outside Totality Belt)								Group III (Observatory Stations Outside Totality Belt)										
	1. Gol.	2. G. R.	3. Cor.	4. Lak.	5. Men.	6. Bre.	7. Orl.	8. Ber.	9. Mor.	9a. Urb.	9b. Col.	10. Aus.	11. Was.	12. Wob.	13. Riv.	25. Wat.	15. Ant.	14. Luk.	16. Kak.	18. Hon.	19. Sit.	20. Mea.	21. Tuc.	22. Agi.	23. Che.	24. P. R.
h m	′	′	′	′	′	′	′	′	′	′	′	′	′	′	′	′	′	′	′	′	′	′	′	′	′	′
19 00	—0.5	+1.0	+1.3	+0.1	0.0	—1.1	—1.0	....	—0.1	....	....	....	—2.0	—3.4	—0.4	+0.3	....	+0.1	+0.2	—0.6	+0.6	—1.4	+0.1	—1.0	—2.2	—0.6
05	0.0	+0.7	+1.1	0.0	—0.3	—1.3	—1.2	....	—0.3	....	....	....	—2.1	—3.4	—0.6	+0.4	....	+0.1	+0.3	—0.4	+0.5	—1.4	+0.2	—1.3	—2.4	—0.4
10	—0.7	+0.6	+1.0	0.0	—0.6	—1.3	—1.3	—2.5	—0.5	....	....	....	—2.2	—3.3	—0.7	+0.5	....	+0.2	+0.3	—0.4	+0.3	—2.1	+0.2	—1.5	—2.5	—0.4
15	—0.7	+0.4	+0.9	—0.1	—0.8	—1.1	—1.0	—2.6	—0.6	....	....	+0.4	—2.2	—3.0	0.0	+0.5	....	+0.2	+0.3	—0.6	+0.2	—2.0	0.0	—1.6	—2.6	—0.4
20	—1.2	+0.2	+0.8	—0.4	—1.0	—1.2	—1.2	—2.8	—0.8	....	....	+0.4	—2.3	—3.3	—0.1	+0.5	....	+0.2	+0.3	—0.5	—0.1	—2.9	—0.1	—1.7	—2.5	—0.3
25	—1.2	0.0	+0.7	—0.2	—1.0	—1.6	—1.0	—3.0	—0.8	....	....	+0.3	—2.2	—3.8	0.0	+0.3	+0.1	+0.1	+0.3	—0.4	—0.5	—2.8	—0.1	—1.6	—2.5	—0.3
30	—1.6	—0.2	+0.6	—0.1	—1.2	—1.6	—1.0	—3.1	—0.9	....	....	+0.1	—2.3	—3.5	—0.1	+0.3	+0.1	+0.1	+0.3	—0.4	—1.2	—3.0	—0.1	—2.0	—2.4	—0.3
35	—1.8	—0.3	+0.4	—0.1	—1.3	—1.5	—1.1	—3.2	—1.2	....	....	0.0	—2.3	—3.8	0.0	+0.4	+0.1	+0.2	+0.3	—0.6	—1.8	—4.0	—0.2	—1.9	—2.5	—0.2
40	—2.0	—0.2	—0.2	0.0	—1.4	—1.1	—1.2	—3.0	—1.2	....	....	—0.2	—2.1	—3.3	—0.1	+0.3	—0.1	+0.2	+0.1	—0.5	—2.2	—3.8	—0.3	—2.0	—2.5	—0.2
45	—2.2	—0.3	—0.5	0.0	—1.1	—1.0	—1.1	—2.8	—1.3	....	....	—0.2	—1.7	—2.8	+0.7	+0.2	—0.3	+0.2	—0.1	—0.4	—2.7	—3.7	—0.2	—1.8	—2.3	—0.1
50	—2.1	—0.3	—0.6	+0.1	—0.9	—0.7	—0.9	—2.7	—1.0	....	....	—0.3	—1.6	—2.6	+1.7	+0.1	—0.3	+0.2	—0.1	—0.3	—3.0	—3.4	—0.1	—1.2	—2.0	0.0
55	—2.0	0.0	—0.3	+0.5	—0.7	—0.6	—0.8	—2.7	—0.7	....	....	—0.3	—1.1	—2.0	+2.9	+0.1	—0.3	+0.1	—0.2	—0.2	—3.0	—2.5	—0.1	—0.8	—1.5	+0.2
20 00	—2.1	0.0	—0.3	+0.8	—0.6	—0.5	—0.8	—2.7	—0.5	....	+1.9	—0.3	—0.8	—1.7	+3.1	+0.1	—0.3	0.0	—0.3	—0.1	—2.8	—2.0	—0.1	—0.6	—1.1	+0.3
05	—1.8	+0.2	—0.5	+1.1	—0.4	—0.4	—0.6	—2.8	—0.2	....	+1.9	—0.4	—0.6	—1.3	+4.0	0.0	—0.3	—0.2	—0.4	0.0	—2.7	—1.1	—0.1	—0.2	—0.7	+0.4
10	—1.8	+0.4	—0.5	+0.9	—0.2	—0.2	—0.7	—3.0	0.0	....	+2.2	—0.3	—0.1	—0.5	+4.9	—0.1	—0.3	—0.1	—0.5	0.0	—2.3	—0.8	—0.1	+0.5	—0.4	+0.4
15	—1.8	+0.4	—0.7	+1.1	0.0	0.0	—0.8	—3.4	+0.1	....	+2.0	—0.4	—0.1	—0.3	+5.0	—0.1	—0.3	—0.1	—0.5	0.0	—1.9	—0.5	+0.1	+0.7	—0.4	+0.5
20	—2.0	+0.2	—1.2	+1.1	0.0	—0.1	—0.5	—3.8	+0.1	....	+2.0	—0.1	—0.1	—0.5	+4.4	0.0	—0.3	—0.1	—0.4	+0.1	—1.4	—1.3	+0.1	+0.4	—0.4	+0.6
25	—2.3	—0.1	—1.4	+0.8	0.0	—0.1	—0.3	—3.9	—0.1	....	+1.8	—0.2	—0.2	—0.8	+3.8	0.0	—0.1	0.0	—0.2	0.0	—1.5	—2.6	—0.1	0.0	—0.5	+0.6
30	—2.8	—0.3	—1.4	+0.4	—0.2	—0.4	—0.4	—4.4	—0.3	....	+1.7	—0.1	—0.6	—1.1	+2.5	0.0	—0.1	+0.2	—0.1	—0.1	—2.2	—3.6	—0.1	—0.7	—0.7	+0.7
35	—3.0	—0.3	—1.0	+0.1	—0.3	—0.5	—0.5	—4.4	—0.4	....	+1.1	—0.2	—0.7	—1.3	+2.6	+0.1	—0.1	+0.3	0.0	+0.1	—1.6	—2.8	—0.1	—0.7	—0.8	+0.7
40	—3.0	—0.6	+0.1	—0.2	—0.3	—0.6	—0.6	—4.0	—0.7	....	+1.3	—0.4	—0.6	—0.9	+3.1	+0.3	+0.1	+0.3	+0.1	+0.2	—1.6	—2.2	—0.3	—0.5	—0.9	+0.6
45	—2.9	—0.9	+0.5	—0.2	—0.4	—1.1	—0.6	—3.9	—0.7	....	+0.9	—0.4	—0.7	—0.6	+3.7	+0.3	+0.1	+0.3	+0.1	+0.2	—1.2	—2.0	—0.4	—0.7	—0.9	+0.5
50	—2.7	—0.6	+0.8	—0.2	—0.1	—0.6	—0.5	—4.4	—0.5	....	+1.0	—0.3	—0.4	—0.5	+4.0	+0.2	+0.1	+0.2	—0.1	+0.2	—1.4	—1.8	—0.3	—0.6	—0.8	+0.6
55	—2.6	—0.5	+1.0	—0.2	—0.1	—0.2	—0.3	—4.4	—0.6	....	+1.2	—0.2	—0.3	—0.7	+4.7	+0.1	+0.1	+0.2	—0.1	+0.3	—1.1	—1.3	—0.1	—0.4	—0.4	+0.8
21 00	—1.9	—0.1	+1.4	0.0	+0.3	—0.3	+0.1	—3.8	—0.1	....	+1.2	—0.1	0.0	0.0	+5.9	—0.1	+0.1	+0.1	—0.2	+0.4	—0.2	+0.2	+0.1	+0.2	—0.2	+0.8
05	—1.4	+0.1	+2.0	+0.5	+0.6	+0.1	+0.2	—3.6	+0.1	....	+1.5	+0.2	+0.5	+0.5	+7.1	—0.1	+0.1	—0.3	—0.2	+0.2	+1.0	+1.5	+0.3	+1.0	+0.3	+1.0
10	—1.3	+0.3	+2.2	+0.6	+0.9	+0.4	+0.5	—3.7	+0.2	....	+1.4	+0.5	+0.9	+1.1	+7.6	—0.1	0.0	—0.1	—0.1	+0.2	+0.5	+0.8	+0.4	+1.5	+0.8	+1.1
15	—1.6	+0.5	+2.2	+0.6	+0.9	+0.4	+0.6	—3.9	+0.5	....	+1.1	+0.4	+0.6	+0.4	+6.0	0.0	+0.1	0.0	+0.1	+0.2	—0.7	+0.4	+0.5	+0.7	+0.4	+1.2
20	—1.3	+0.5	+2.0	+0.6	+0.7	+0.7	+0.6	—4.2	+0.4	....	+0.5	+0.4	+0.4	—0.2	+4.8	0.0	+0.3	0.0	+0.5	+0.2	—0.9	—0.5	+0.5	+0.4	+0.4	+1.1
25	—1.7	+0.3	+1.2	+0.7	+0.6	+0.5	+0.5	—4.3	0.0	....	+0.7	+0.5	+0.3	—0.9	+4.4	+0.1	+0.3	—0.1	+0.7	+0.2	—1.0	—1.1	+0.4	+0.1	+0.2	+1.1
30	—1.8	+0.1	+1.0	+0.7	+0.5	+0.3	+0.6	—4.3	—0.1	....	+0.6	+0.3	+0.3	—0.7	+4.3	+0.1	+0.4	+0.3	+0.4	+0.2	—1.5	—1.1	+0.4	+0.1	+0.2	+1.0
35	—1.9	0.0	+0.4	+0.6	+0.6	0.0	+0.6	—4.2	—0.3	....	+0.6	+0.3	+0.3	—1.0	+4.2	+0.1	+0.4	+0.4	+0.5	+0.1	—1.5	—1.0	+0.4	0.0	+0.3	+1.0
40	—1.5	—0.1	+0.1	+0.5	+0.6	+0.2	+0.5	—3.8	—0.3	....	+0.5	+0.3	0.0	—1.1	+3.9	0.0	+0.5	+0.3	+0.5	0.0	—1.0	—1.7	+0.3	—0.2	+0.2	+1.0
45	—2.1	—0.4	—0.7	+0.4	+0.5	—0.2	+0.7	—3.4	—0.7	—2.5	+0.1	+0.1	0.0	—1.7	+3.4	+0.1	+0.5	+0.3	+0.6	—0.1	—1.0	—2.8	+0.3	—0.5	+0.1	+0.9
50	—2.1	—0.5	—1.0	+0.1	+0.1	—0.4	+0.8	—3.0	—0.6	—2.9	+0.2	+0.1	+0.1	—2.1	+2.7	+0.1	+0.7	+0.5	+0.7	—0.1	—0.7	—2.4	+0.2	—0.6	0.0	+0.8
55	—2.3	—1.0	—1.1	—0.2	—0.2	—0.3	+0.4	—2.9	—1.0	—3.0	—0.6	—0.1	—0.3	—2.1	+2.5	+0.1	+0.8	+0.7	+0.9	—0.1	—0.4	—2.0	—0.1	—0.9	—0.2	+0.7

TABLE 9.—*Declination effects, or values of Δ D, June 8, 1918.*—Continued.

G.M.T.	Group I (Totality Stations)							Group II (Field Stations Outside Totality Belt)								Group III (Observatory Stations Outside Totality Belt)										
	1. Gol.	2. G. R.	3. Cor.	4. Lak.	5. Men.	6. Bre.	7. Orl.	8. Ber.	9. Mor.	9a. Urb.	9b. Col.	10. Aus.	11. Was.	12. Wob.	13. Riv.	25. Wat.	15. Ant.	14. Luk.	16. Kak.	18. Hon.	19. Sit.	20. Mea.	21. Tuc.	22. Agi.	23. Che.	24. P. R.
h m	′	′	′	′	′	′	′	′	′	′	′	′	′	′	′	′	′	′	′	′	′	′	′	′	′	′
22 00	−1.9	−1.0	−0.9	−0.5	−0.2	−0.3	+0.4	−3.3	−1.1	−2.7	−0.5	−0.1	+0.1	−2.2	+3.0	+0.1	+0.7	+0.5	+0.8	−0.1	0.0	−0.8	−0.1	−0.5	−0.2	+0.7
05	−1.7	−0.7	−0.8	−0.4	−0.3	+0.1	+0.3	−3.4	−1.0	−2.3	−0.3	−0.1	−0.1	−2.5	+3.2	+0.1	+0.6	+0.2	+0.6	−0.1	0.0	−0.3	−0.1	−0.4	−0.2	+0.7
10	−1.5	−0.4	−0.2	−0.1	−0.3	+0.1	+0.6	−3.0	−0.6	−2.4	−0.1	0.0	−0.2	−2.0	+2.9	0.0	+0.6	+0.2	+0.5	−0.1	0.0	0.0	−0.1	−0.4	0.0	+0.6
15	−1.2	−0.3	+0.2	−0.1	−0.2	+0.1	+0.6	−2.6	−0.5	−1.9	−0.1	−0.2	0.0	−2.4	+2.7	+0.1	+0.7	+0.2	+0.4	−0.1	+0.1	+0.7	+0.1	−0.5	+0.1	+0.6
20	−1.2	−0.4	+0.6	0.0	−0.2	+0.1	+0.4	−2.2	−0.2	−2.2	−0.4	−0.3	−0.3	−3.0	+2.3	0.0	+0.7	+0.2	+0.4	−0.1	+0.4	+0.8	+0.4	−0.5	0.0	+0.6
25	−0.9	−0.2	+1.0	−0.1	−0.2	+0.2	+0.4	−1.9	0.0	−1.6	−0.6	−0.1	−0.3	−3.0	+1.6	−0.1	+0.6	+0.3	+0.3	−0.1	+0.6	+1.0	+0.5	−0.6	−0.1	+0.5
30	−1.0	−0.2	+1.2	−0.2	−0.4	0.0	+0.3	−1.8	0.0	−1.8	−0.3	−0.2	−0.2	−2.3	+1.5	0.0	+0.5	+0.3	+0.4	−0.1	+0.6	+1.1	+0.6	−0.7	−0.2	+0.4
35	−0.7	0.0	+1.4	−0.1	−0.4	0.0	+0.3	−1.6	+0.1	−1.6	−0.2	−0.3	−0.3	−2.5	+1.2	0.0	+0.5	+0.4	+0.4	−0.1	+0.6	+1.6	+0.7	−0.4	−0.4	+0.4
40	−0.7	−0.1	+1.5	+0.1	−0.3	−0.1	+0.3	−1.3	+0.2	−1.3	−0.2	−0.2	−0.3	−2.3	+1.0	0.0	+0.5	+0.2	+0.4	−0.1	+0.6	+1.9	+0.7	−0.5	−0.4	+0.3
45	−0.9	−0.1	+1.9	+0.1	−0.4	−0.1	+0.3	−1.1	+0.3	−0.9	−0.1	−0.3	−0.4	−3.3	+0.5	0.0	+0.4	+0.1	+0.3	0.0	−0.1	+1.6	+0.7	−0.6	−0.3	+0.3
50	−0.7	0.0	+1.8	0.0	−0.3	−0.1	+0.3	−1.0	+0.2	0.0	−0.2	−0.2	−0.2	−3.0	+0.3	0.0	+0.3	−0.1	+0.2	0.0	0.0	+1.4	+0.8	−0.5	−0.4	+0.1
55	−0.7	0.0	+1.3	+0.1	−0.4	−0.3	+0.4	−1.0	+0.4	+0.2	−0.3	−0.1	−0.3	−3.2	+0.4	0.0	+0.2	−0.2	+0.1	0.0	−0.4	+1.3	+0.9	−0.8	−0.4	+0.1
23 00	−0.7	−0.1	+1.3	+0.2	−0.5	−0.2	+0.3	−1.0	+0.4	+0.2	−0.3	−0.2	−0.3	−3.3	+0.3	+0.1	+0.1	−0.3	0.0	+0.2	−0.6	+1.4	+0.9	−0.6	−0.4	−0.1
05	−0.8	−0.2	+1.0	+0.3	−0.4	−0.1	+0.3	−1.0	+0.3	+0.5	−0.4	−0.1	−0.3	−3.1	+0.2	+0.2	+0.1	−0.3	−0.1	+0.2	−0.5	+1.5	+0.9	−0.6	−0.3	−0.1
10	−0.8	−0.1	+0.9	+0.5	−0.4	−0.2	+0.1	−0.9	+0.4	0.0	−0.4	−0.1	0.0	−3.1	+0.2	+0.3	+0.1	−0.3	−0.1	+0.2	−0.5	+1.4	+1.0	−0.5	−0.4	−0.1
15	−0.8	+0.1	+0.7	+0.6	−0.2	−0.2	+0.2	−0.9	+0.4	+0.5	−0.5	0.0	−0.1	−2.8	+0.3	+0.3	+0.1	−0.3	−0.4	+0.1	−0.6	+1.4	+0.9	−0.3	−0.4	−0.1
20	−0.7	+0.1	+0.7	+0.6	−0.4	−0.2	+0.2	−1.0	+0.5	0.0	−0.7	0.0	−0.3	−2.4	+0.8	+0.2	−0.2	−0.3	−0.6	+0.2	−0.5	+1.4	+1.1	−0.6	−0.4	−0.1
25	−0.5	+0.2	+0.6	+0.5	−0.5	−0.2	+0.1	−1.2	+0.5	+0.5	−0.6	0.0	+0.3	−1.6	+1.0	+0.3	−0.2	−0.4	−0.7	+0.2	−0.2	+1.6	+0.9	0.0	−0.4	−0.1
30	−0.9	+0.1	+0.3	+0.4	−0.6	−0.2	0.0	−1.5	+0.5	+0.4	−0.3	+0.1	+0.2	−1.6	+1.1	+0.2	−0.2	−0.4	−0.4	+0.3	−0.1	+1.3	+0.9	+0.1	−0.2	−0.1
35	−0.8	−0.1	+0.8	+0.3	−0.6	0.0	+0.1	−1.4	+0.4	+0.7	−0.4	−0.1	+0.4	−0.3	+1.4	+0.1	−0.2	−0.4	−0.3	+0.2	−0.3	+0.9	+0.8	+0.4	−0.1	−0.1
40	−0.8	0.0	+1.4	+0.5	−0.4	−0.3	+0.1	−1.3	+0.4	+0.6	−0.6	−0.2	+0.5	−1.0	+1.4	+0.2	−0.3	−0.3	−0.5	+0.3	−0.3	+0.6	+0.8	+0.6	+0.1	−0.1
45	−1.0	+0.1	+1.6	+0.4	−0.4	−0.5	−0.1	−1.3	+0.6	+0.4	−0.4	0.0	+0.6	−2.1	+1.0	+0.1	−0.3	−0.3	−0.8	+0.4	−0.2	+0.5	+0.8	+0.3	+0.1	0.0
50	−0.7	+0.3	+1.5	+0.2	−0.4	−0.6	+0.3	−1.3	+0.6	+0.6	−0.4	+0.3	+0.7	−2.5	+0.5	+0.1	−0.4	−0.5	−1.2	+0.5	−0.3	+0.4	+0.8	+0.4	+0.2	0.0
55	−0.4	+0.6	+1.5	+0.1	−0.4	−0.8	+0.6	−1.3	+0.7	+0.4	−0.3	+0.4	+0.5	−2.8	−0.2	0.0	−0.6	−0.7	−1.3	+0.5	−0.2	+0.8	+1.0	+0.1	+0.1	−0.1
24 00	−0.5	+0.6	+1.3	+0.1	−0.5	−0.5	+0.9	−1.3	+0.5	+1.1	−0.4	+0.3	+0.7	−2.3	+0.6	−0.1	−0.6	−0.8	−1.2	+0.6	0.0	+1.0	+1.0	+0.8	+0.3	0.0
05	−0.4	+0.5	+1.2	+0.3	−0.5	−0.4	+1.1	−1.3	+0.5	+1.6	−0.2	+0.5	+0.9	−2.4	+1.3	0.0	−0.5	−0.7	−0.9	+0.7	+0.2	+1.2	+1.0	+1.0	+0.3	+0.1
10	−0.1	+0.5	+1.0	+0.3	−0.5	−0.2	+1.2	−1.3	+0.6	+1.7	−0.1	+0.5	+1.1	−1.8	+1.0	0.0	−0.5	−0.6	−0.7	+0.9	+0.3	+1.6	+1.0	+1.1	+0.4	+0.1
15	0.0	+0.8	+1.4	+0.7	−0.2	+0.1	+1.3	−1.2	+0.8	+1.5	0.0	+0.6	+0.9	−1.7	+0.8	+0.1	−0.5	−0.6	−0.3	+1.1	+0.3	+1.8	+1.2	+1.1	+0.5	+0.2
20	−0.2	+0.8	+1.5	+0.8	+0.1	+0.5	.....	−1.0	+1.0	+1.6	+0.2	+0.6	+1.1	−1.9	+0.7	−0.1	−0.4	−0.6	0.0	+1.2	0.0	+1.1	+1.2	+1.2	+0.5	+0.3
25	−0.6	+0.9	+1.8	+1.3	+0.3	+0.8	.....	−1.1	+1.0	+2.1	+0.2	+0.7	+1.1	−2.0	+0.8	−0.2	−0.4	−0.5	0.0	+1.3	−0.3	+0.7	+1.2	+1.2	+0.6	+0.3
30	−0.7	+1.0	+2.0	+1.4	+0.5	+1.0	.....	−1.3	+1.1	+2.1	+0.1	+0.6	+1.1	−1.5	+0.8	0.0	−0.3	−0.4	0.0	+1.2	−0.2	+0.7	+1.3	+1.2	+0.7	+0.3
35	−0.6	+0.9	+2.1	+1.5	+0.5	+1.0	.....	−1.6	+1.1	+2.1	0.0	+0.6	+1.2	−1.6	+0.6	+0.2	−0.3	−0.4	0.0	+1.2	−0.2	+0.6	+1.2	+1.0	+0.8	+0.3
40	−0.7	+0.9	+2.0	+1.4	+0.4	+1.0	.....	−1.8	+1.1	+1.7	−0.1	+0.7	+1.3	−1.9	+0.6	+0.1	−0.3	−0.4	−0.1	+1.4	−0.2	+0.6	+1.2	+0.9	+0.7	+0.3
45	−0.7	+0.9	+1.6	+1.0	+0.4	+0.8	.....	−1.9	+1.0	+1.6	−0.4	+0.7	+1.0	−1.7	−0.2	+0.1	−0.4	−0.3	−0.3	+1.4	0.0	+0.7	+1.1	+0.4	+0.7	+0.2
50	−1.0	+0.4	+1.1	+0.9	+0.2	+0.6	.....	−1.9	+0.8	+1.6	−0.8	+0.7	+0.7	−2.4	−0.7	−0.1	−0.4	−0.2	−0.3	+1.3	0.0	+0.2	+1.0	0.0	+0.7	+0.1
55	−1.2	+0.3	+0.5	+0.7	+0.3	+0.8	.....	−1.9	+0.5	+1.0	−1.1	+0.6	+0.8	−2.4	−0.4	−0.6	.....	−0.1	−0.2	+1.3	−0.2	−0.2	+0.8	−0.1	+0.5	+0.1
25 00	−1.4	+0.4	+0.5	+0.7	+0.4	+1.0	.....	.....	+0.6	.....	−1.4	+0.6	+0.9	−2.3	−0.3	−0.5	.....	0.0	−0.2	+1.3	−0.5	−0.3	+0.7	0.0	+0.2	+0.1

36. Let us begin with the most westerly station, *Kakioka*, the fourth curve of Fig. 9, where the entire eclipse took place, viz., from $19^h\ 46^m$ to $21^h\ 42^m$ G. M. T., June 8, or $5^h\ 07^m$ to $7^h\ 03^m$ L. M. T., June 9, the maximum obscuration (0.88) occurring at about $20^h\ 41^m$ G. M. T., or $6^h\ 02^m$ L. M. T. As the eclipse began on the Earth at $19^h\ 29^m$ G. M. T., the eclipse began at Kakioka only 17 minutes later and this station was thus near the line of beginning of the eclipse. Consulting the Kakioka data, *Terr. Mag.*, vol. 23, Table 1, p. 152, it will be seen that west declination diminishes almost steadily during the period 19^h to about 22^h G. M. T., June 7, viz., from 5° 20′.9 W to 5° 18′.9 W; in other words, during the period of eclipse at Kakioka the declination needle would normally have been approaching the morning elongation or maximum easterly position (minimum west declination). However, when the eclipse began, the normal course on June 8 was interrupted, the needle was deflected to the west so that west declination began to increase again until a bay was formed at about $20^h\ 10^m$ (see Figs. 8 and 9). The small waves which made their appearance during the eclipse are also clearly discernible in the reproduction of the Kakioka magnetogram (see *Terr. Mag.*, vol. 23, p. 153, Fig. 1).

37. Passing next to *Sitka*, where the magnetic declination was about 30°.4 E, we find (Table 5) that the eclipse occurred from $21^h\ 13^m$ to $23^h\ 40^m$ G. M. T., or from $12^h\ 12^m$ to $14^h\ 39^m$ L. M. T. The maximum obscuration (0.75) occurred at $22^h\ 27^m$ G. M. T., or $13^h\ 26^m$ L. M. T. As judged from the 10 magnetically-quiet days in June, the afternoon elongation (minimum east declination of about 30° 15′) would normally have occurred at about $23^h\ 55^m$ G. M. T., or $14^h\ 54^m$ L. M. T. Hence, normally during the eclipse-period east declination would have been steadily diminishing. Looking at Fig. 8, however, we see that at about $21^h\ 35^m$ G. M. T., or at about 22 minutes after the beginning of the eclipse, the normal downward trend of the curve is interrupted, an upward movement sets in which continues for about an hour before the downward course (diminishing east declination) is resumed. The wave of period about 1.5 hours during the eclipse interval, is clearly shown in Fig. 9.

38. *Effects similar to those described for Sitka occurred at several stations in the western part of North America;* see, for example, Meanook, Goldendale, and Berkeley, Figs. 7, 8, and 9. As the eclipse, in its southeastward progression across the United States,

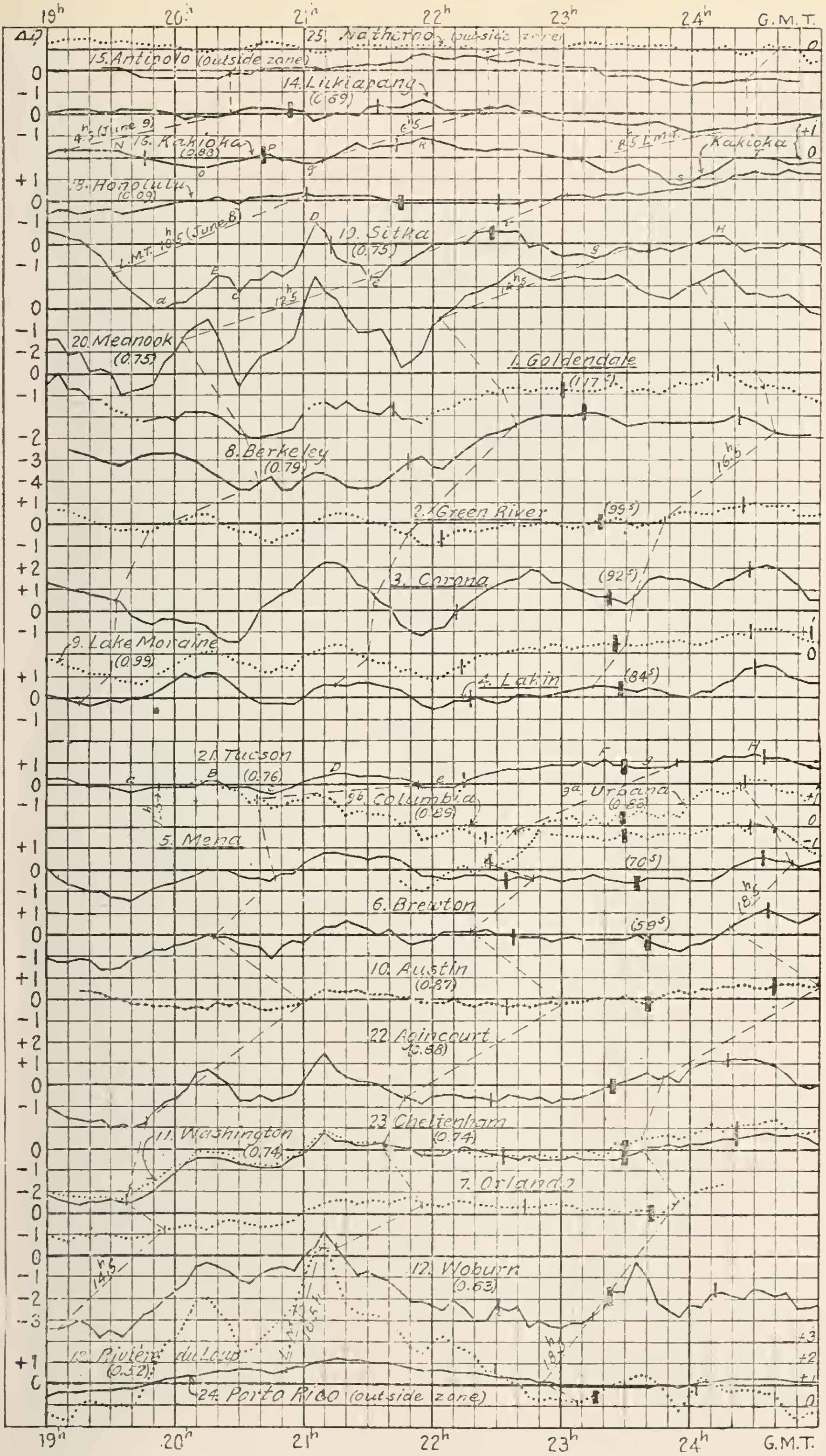

FIG. 9.—ΔD-Curves, Solar Eclipse, June 8, 1918.

occurred later and later in the afternoon, effects on the declin-ation-needle are still found discernible, though their character is modified (see Fig. 9).

39. Returning now to the first three curves of Fig. 9, we find indications of the wave, which made its appearance during the eclipse at Kakioka, at *Lukiapang* (China) where maximum obscuration occurred at sunrise, *Antipolo* (Philippines), just outside the eastern edge of the zone of visibility, and even at *Watheroo* (Western Australia). The retrogressive effect, or tendency towards a depression, or bay, is also shown for these stations in Fig. 8, between 20^h and $20^h\ 15^m$ G. M. T.

40. We thus have clear evidence that *the first effect of a solar eclipse is that of an interruption and retrogression in the normal diurnal variation.* This is in complete accord with the effect which we had found for previous eclipses. We also find again that, while there is a distinct and characteristic wave during the local eclipse-interval, the effects are not confined to the shadow belt but occur over a large region—over the entire zone of visibility and, even in diminished degree, beyond.

41. Since the effect travels rapidly over a large area, we may have an accumulation or heaping up of *preliminary effects* at any one station, which make their appearance *before* the eclipse occurs at that station; these preliminary effects would originate chiefly from the region, west of our station, over which the eclipse had already occurred, or is occurring at the time. The most striking and universal preliminary effect for North American stations is the one to which attention has already been directed in paragraph 29, viz., the prominent crest shortly after 21^h (see Figs. 7, 8, and 9). This crest is so distinctly defined at many of the stations as to resemble seemingly a sudden perturbation which occurred nearly simultaneously over a large portion of the Earth. Since the declination readings at the field stations were taken every minute of time, it is possible to determine the time of occurrence of this particular crest at most of the stations within about 2 minutes. The times are given in Table 11 not only for this crest, designated as D, but also the preceding trough c, the preceding crest B, and the trough a, preceding B. There are furthermore given in Table 11 the times of occurrence of troughs and crests, subsequent to D, which could be fairly well identified at certain stations, viz., e, F, g and H. The selected salient points are marked for the stations Sitka and Tucson, Fig. 9. It will be noticed that

the troughs (lows) are designated by small letters and the crests (highs) by capital letters. Sometimes instead of a single trough or crest, there may be two or three within an interval of 10 to 30 minutes; in such cases the average time of the multiple points is taken and the time thus derived is italicized in Table 11. The times as given in the table are determined from a consideration of the curves, Figs. 7, 8, and 9., the eye-readings, and the times determined by Mr. Hazard from the magnetograms of the Coast and Geodetic Survey observatories.

Remarks on the $H\triangle D$-Curves.

42. Fig. 10 gives a diagrammatic representation of the variations in the deflecting force ($H\triangle D$), acting approximately at right angles to the compass direction. Not all the stations are represented in this diagram, such as shown, for example, in Fig. 9; only typical ones are selected in order to exhibit readily the chief characteristic features. The quantities were derived from Table 9, expressing $\triangle D$ in circular measure and multiplying by the value of H from Table 5; they are given in Table 10. As a first approximation the $\triangle D$-effects vary inversely as the value of H. Hence, by multiplying the $\triangle D$'s by H, we reduce the $\triangle D$-curves, given in Fig. 9, to the same scale approximately; we may, accordingly, form a better idea from the $H\triangle D$-curves of the relative declination effects from station to station than from the $\triangle D$-curves. A broken curve indicates that for the station to which it applies the normal curve from which the magnetic effects were reckoned had to be deduced from the diurnal-variation data at neighboring stations (see paragraph 35).

43. The first three curves (Antipolo, Lukiapang and Kakioka) show closely identical features, which often, however, are opposite to those shown by the succeeding curves. Thus, for example, the prominent crest between 21^h and $21^h\ 30^m$ exhibited by the curves from Honolulu to Porto Rico corresponds to a trough at the stations, Antipolo to Kakioka; the general rise to a crest near 22^h at the latter stations corresponds to a trough generally at the former stations.

44. While the range of the effects shown in the present curves (Fig. 10) is more equalized than for the $\triangle D$-curves (Fig. 9), there is still a tendency towards increased range with decrease in H or increase in magnetic latitude of station (see Sitka and Meanook, for example). The *mountain station, Corona* (*altitude 11,800 feet*),

TABLE 10.—*Five-minute values of $H\Delta D$ for selected stations, June 8, 1918.*

G.M.T.	Ant.	Luk.	Kak.	Hon.	Sit.	Mea.	Gol.	G.R.	Cor.	Mor.	Lak.	Tuc.	Agi.	Che.	P. R.
h m	γ	γ	γ	γ	γ	γ	γ	γ	γ	γ	γ	γ	γ	γ	γ
19 00	.....	+1.0	+1.7	−5.0	+2.7	−5.2	−2.9	+6.2	+8.4	−0.6	+0.8	+1.6	−4.6	−12.3	−4.9
05	.....	+1.0	+2.6	−3.4	+2.3	−5.2	0.0	+4.3	+7.1	−1.9	+0.1	+1.6	−6.0	−13.4	−3.3
10	.....	+1.9	+2.6	−3.4	+1.4	−7.9	−4.1	+3.7	+6.4	−3.2	+0.1	+1.6	−6.9	−14.0	−3.3
15	.....	+1.9	+2.6	−5.0	+0.9	−7.5	−4.1	+2.5	+5.8	−3.9	−0.8	0.0	−7.4	−14.6	−3.3
20	.....	+1.9	+2.6	−4.2	−0.5	−10.9	−7.0	+1.2	+5.2	−5.2	−2.3	−0.8	−7.9	−14.0	−2.4
25	+1.1	+1.0	+2.6	−3.4	−2.3	−10.5	−7.0	0.0	+4.5	−5.2	−1.6	−0.8	−7.4	−14.0	−2.4
30	+1.1	+1.0	+2.6	−3.4	−5.4	−11.2	−9.4	−1.2	+3.9	−5.8	−0.8	−0.8	−9.2	−13.4	−2.4
35	+1.1	+1.9	+2.6	−5.0	−8.2	−15.0	−10.5	−1.9	+2.6	−7.8	−0.8	−1.6	−8.8	−14.0	−1.6
40	−1.1	+1.9	+0.9	−4.2	−10.0	−14.2	−11.7	−1.2	−1.3	−7.8	−0.1	−2.4	−9.2	−14.0	−1.6
45	−3.3	+1.9	−0.9	−3.4	−12.3	−13.9	−12.9	−1.9	−3.2	−8.4	−0.1	−1.6	−8.3	−12.9	−0.8
50	−3.3	+1.9	−0.9	−2.5	−13.6	−12.8	−12.3	−1.9	−3.9	−6.5	+0.8	−0.8	−5.5	−11.2	0.0
55	−3.3	+1.0	−1.7	−1.7	−13.6	−9.4	−11.7	0.0	−1.9	−4.5	+3.1	−0.8	−3.7	−8.4	+1.6
20 00	−3.3	0.0	−2.6	−0.8	−12.7	−7.5	−12.3	0.0	−1.9	−3.2	+5.5	−0.8	−2.8	−6.2	+2.4
05	−3.3	−1.9	−3.5	0.0	−12.3	−4.1	−10.5	+1.2	−3.2	−1.3	+7.1	−0.8	−0.9	−3.9	+3.3
10	−3.3	−1.0	−4.3	0.0	−10.4	−3.0	−10.5	+2.5	−3.2	0.0	+6.2	−0.8	+2.3	−2.2	+3.3
15	−3.3	−1.0	−4.3	0.0	−8.6	−1.9	−10.5	+2.5	−4.5	+0.6	+7.0	+0.8	+3.2	−2.2	+4.1
20	−3.3	−1.0	−3.5	+0.8	−6.4	−4.9	−11.7	+1.2	−7.7	+0.6	+7.0	+0.8	+1.8	−2.2	+4.9
25	−1.1	0.0	−1.7	0.0	−6.8	−9.8	−13.4	−0.6	−9.0	−0.6	+5.5	−0.8	0.0	−2.8	+4.9
30	−1.1	+1.9	−0.9	−0.8	−10.0	−13.5	−16.4	−1.9	−9.0	−1.9	+2.3	−0.8	−3.2	−3.9	+5.7
35	−1.1	+2.9	0.0	+0.8	−7.3	−10.5	−17.5	−1.9	−6.4	−2.6	+0.7	−0.8	−3.2	−4.5	+5.7
40	+1.1	+2.9	+0.9	+1.7	−7.3	−8.2	−17.5	−3.7	+0.6	−4.5	−1.6	−2.4	−2.3	−5.0	+4.9
45	+1.1	+2.9	+0.9	+1.7	−5.4	−7.5	−17.0	−5.6	+3.2	−4.5	−1.6	−3.1	−3.2	−5.0	+4.1
50	+1.1	+1.9	−0.9	+1.7	−6.4	−6.8	−15.8	−3.7	+5.2	−3.2	−1.6	−2.4	−2.8	−4.5	+4.9
55	+1.1	+1.9	−0.9	+2.5	−5.0	−4.9	−15.2	−3.1	+6.4	−3.9	−1.6	−0.8	−1.8	−2.2	+6.5
21 00	+1.1	+1.0	−1.7	+3.4	−0.9	+0.8	−11.1	−0.6	+9.0	−0.6	0.0	+0.8	+0.9	−1.1	+6.5
05	+1.1	−2.9	−1.7	+1.7	+4.5	+5.6	−8.2	+0.6	+12.9	+0.6	+3.2	+2.4	+4.6	+1.7	+8.2
10	0.0	−1.0	−0.9	+1.7	+2.3	+3.0	−7.6	+1.8	+14.2	+1.3	+3.9	+3.1	+6.9	+4.5	+9.0
15	+1.1	0.0	+0.9	+1.7	−3.2	+1.5	−9.4	+3.0	+14.2	+3.2	+3.9	+3.9	+3.2	+2.2	+9.8
20	+3.3	0.0	+4.3	+1.7	−4.1	−1.9	−7.6	+3.0	+12.9	+2.6	+3.9	+3.9	+1.8	+2.2	+9.0
25	+3.3	−1.0	+6.0	+1.7	−4.5	−4.1	−9.9	+1.8	+7.7	0.0	+4.7	+3.1	+0.5	+1.1	+9.0
30	+4.4	+2.9	+3.5	+1.7	−6.8	−4.1	−10.5	+0.6	+6.4	−0.6	+4.7	+3.1	+0.5	+1.1	+8.2
35	+4.4	+3.9	+4.3	+0.8	−6.8	−3.8	−11.1	0.0	+2.6	−1.9	+3.7	+3.1	0.0	+1.7	+8.2
40	+5.6	+2.9	+4.3	0.0	−4.5	−6.4	−8.8	−0.6	+0.6	−1.9	+3.0	+2.4	−0.9	+1.1	+8.2
45	+5.6	+2.9	+5.2	−0.8	−4.5	−10.5	−12.3	−2.5	−4.5	−4.5	+2.4	+2.4	−2.3	+0.6	+7.3
50	+7.8	+4.8	+6.0	−0.8	−3.2	−9.0	−12.3	−3.1	−6.4	−3.9	+0.8	+1.6	−2.8	0.0	+6.5
55	+8.9	+6.8	+7.8	−0.8	−1.8	−7.5	−13.4	−6.2	−7.1	−6.5	−1.7	−0.8	−4.2	−1.1	+5.7
22 00	+7.8	+4.8	+6.9	−0.8	0.0	−3.0	−11.1	−6.2	−5.8	−7.1	−3.1	−0.8	−2.3	−1.1	+5.7
05	+6.7	+1.9	+5.2	−0.8	0.0	−1.1	−9.9	−4.3	−5.2	−6.5	−2.4	−0.8	−1.8	−1.1	+5.7
10	+6.7	+1.9	+4.3	−0.8	0.0	0.0	−8.8	−2.5	−1.3	−3.9	−0.9	−0.8	−1.8	0.0	+4.9
15	+7.8	+1.9	+3.5	−0.8	+0.5	+2.6	−7.0	−1.9	+1.3	−3.2	−0.8	+0.8	−2.3	+0.6	+4.9
20	+7.8	+1.9	+3.5	−0.8	+1.8	+3.0	−7.0	−2.5	+3.9	−1.3	−0.1	+3.1	−2.3	0.0	+4.9
25	+6.7	+2.9	+2.6	−0.8	+2.7	+3.8	−5.3	−1.2	+6.4	0.0	−0.4	+3.9	−2.8	−0.6	+4.1
30	+5.6	+2.9	+3.5	−0.8	+2.7	+4.1	−5.8	−1.2	+7.7	0.0	−1.1	+4.7	−3.2	−1.1	+3.3
35	+5.6	+3.9	+3.5	−0.8	+2.7	+6.0	−4.1	0.0	+9.0	+0.6	−0.9	+5.5	−1.8	−2.2	+3.3
40	+5.6	+1.9	+3.5	−0.8	+2.7	+7.1	−4.1	−0.6	+9.7	+1.3	+0.7	+5.5	−2.3	−2.2	+2.4
45	+4.4	+1.0	+2.6	0.0	−0.5	+6.0	−5.3	−0.6	+12.3	+1.9	+0.7	+5.5	−2.8	−1.7	+2.4
50	+3.3	−1.0	+1.7	0.0	0.0	+5.2	−4.1	0.0	+11.6	+1.3	−0.1	+6.3	−2.3	−2.2	+0.8
55	+2.2	−1.9	+0.9	0.0	−1.8	+4.9	−4.1	0.0	+8.4	+2.6	+0.7	+7.1	−3.7	−2.2	+0.8
23 00	+1.1	−2.9	0.0	+1.7	−2.7	+5.2	−4.1	−0.6	+8.4	+2.6	+1.4	+7.1	−2.8	−2.2	−0.8
05	+1.1	−2.9	−0.9	+1.7	−2.3	+5.6	−4.7	−1.2	+6.4	+1.9	+2.2	+7.1	−2.8	−1.7	−0.8
10	+1.1	−2.9	−0.9	+1.7	−2.3	+5.2	−4.7	−0.6	+5.8	+2.6	+3.0	+7.8	−2.3	−2.2	−0.8
15	+1.1	−2.9	−3.5	+0.8	−2.7	+5.2	−4.7	+0.6	+4.5	+2.6	+3.8	+7.1	−1.4	−2.2	−0.8
20	−2.2	−2.9	−5.2	+1.7	−2.3	+5.2	−4.1	+0.6	+4.5	+3.2	+3.8	+8.6	−0.5	−2.2	−0.8
25	−2.2	−3.9	−6.0	+1.7	−0.9	+6.0	−2.9	+1.2	+3.9	+3.2	+3.0	+7.1	0.0	−2.2	−0.8
30	−2.2	−3.9	−3.5	+2.5	−0.5	+4.9	−5.3	+0.6	+1.9	+3.2	+3.0	+7.1	+0.5	−1.1	−0.8
35	−2.2	−3.9	−2.6	+1.7	−1.4	+3.4	−4.7	−0.6	+5.2	+2.6	+2.2	+6.3	+1.8	−0.6	−0.8
40	−3.3	−2.9	−4.3	+2.5	−1.4	+2.2	−4.7	0.0	+9.0	+2.6	+3.1	+6.3	+2.8	+0.6	−0.8
45	−3.3	−2.9	−6.9	+3.4	−0.9	+1.9	−5.8	+0.6	+10.3	+3.9	+3.0	+6.3	+1.4	+0.6	0.0
50	−4.4	−4.8	−10.4	+4.2	−1.4	+1.5	−4.1	+1.9	+9.7	+3.9	+1.5	+6.3	+1.8	+1.1	0.0
55	−6.7	−6.8	−11.2	+4.2	−0.9	+3.0	−2.3	+3.7	+9.7	+4.5	+0.7	+7.8	+0.5	+0.6	−0.8
24 00	−6.7	−7.7	−10.4	+5.0	0.0	+3.8	−2.9	+3.7	+8.4	+3.2	+0.6	+7.8	+3.7	+1.7	0.0
05	−5.6	−6.8	−7.8	+5.9	+0.9	+4.5	−2.3	+3.1	+7.7	+3.2	+2.2	+7.8	+4.6	+1.7	+0.8
10	−5.6	−5.8	−6.0	+7.6	+1.4	+6.0	−0.6	+3.1	+6.4	+3.9	+2.2	+7.8	+5.1	+2.2	+0.8
15	−5.6	−5.8	−2.6	+10.1	+1.4	+6.8	0.0	+5.0	+9.0	+5.2	+4.6	+9.4	+5.1	+2.8	+1.6
20	−4.4	−5.8	0.0	+10.1	0.0	+4.1	−1.2	+5.0	+9.7	+6.5	+5.4	+9.4	+5.5	+2.8	+2.4
25	−4.4	−4.8	0.0	+10.9	−1.4	+2.6	−3.5	+5.6	+11.6	+6.5	+8.5	+9.4	+5.5	+3.4	+2.4
30	−3.3	−3.9	0.0	+10.1	−0.9	+2.6	−4.1	+6.2	+12.9	+7.1	+9.3	+10.2	+5.5	+3.9	+2.4
35	−3.3	−3.9	0.0	+10.1	−0.9	+2.2	−3.5	+5.6	+13.5	+7.1	+10.0	+9.4	+4.6	+4.5	+2.4
40	−3.3	−3.9	−0.9	+11.8	−0.9	+2.2	−4.1	+5.6	+12.9	+7.1	+9.2	+9.4	+4.2	+3.9	+2.4
45	−4.4	−2.9	−2.6	+11.8	0.0	+2.6	−4.1	+5.6	+10.3	+6.5	+6.9	+8.6	+1.8	+3.9	+1.6
50	−4.4	−1.9	−2.6	+10.9	0.0	+0.8	−5.8	+2.5	+7.1	+5.2	+6.1	+7.8	0.0	+3.9	+0.8
55	.....	−1.0	−1.7	+10.9	−0.9	−0.8	−7.0	+1.9	+3.2	+3.2	+4.6	+6.3	−0.5	+2.8	+0.8
25 00	.....	0.0	−1.7	+10.9	−2.3	−1.1	−8.2	+2.5	+3.2	+3.9	+4.4	+5.5	0.0	+1.1	+0.8

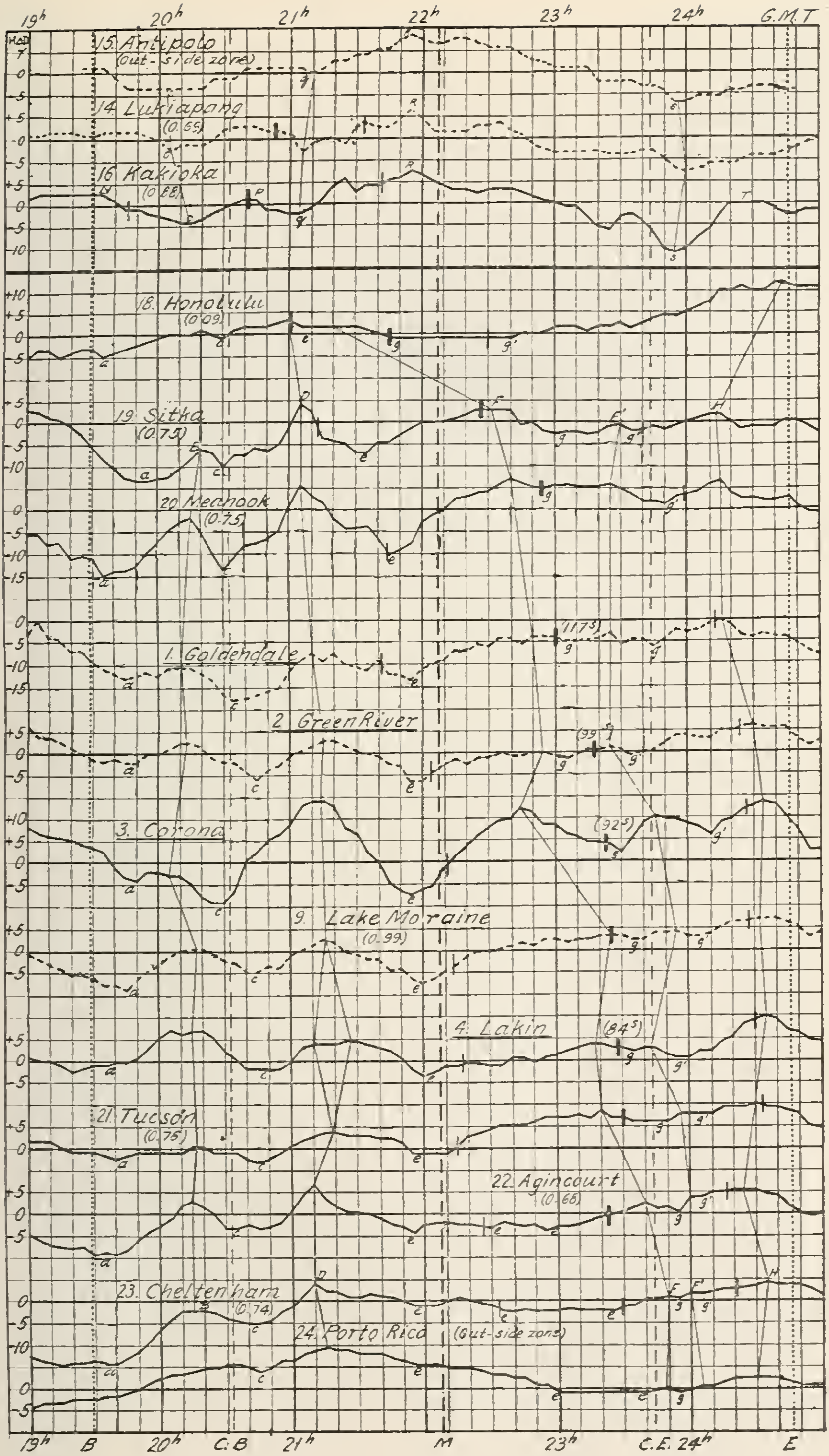

FIG. 10.—$H \Delta D$-Curves, Solar Eclipse, June 8, 1918.

exhibits, however, a striking exception; the absolute range (from highest maximum to lowest minimum) is somewhat greater than at Sitka or at Meanook (see Table 12). This is not chiefly because of the fact that at Corona the eclipse was total, whereas the magnitude of obscuration both at Sitka and Meanook was 0.75.

45. At the nearby totality stations, Green River and Lakin, situated, respectively, to the west and to the east of Corona, the ranges are reduced to about one-half of the Corona curve. The cause for the striking development of the Corona curve is not wholly to be ascribed to altitude either. Thus the curve at the station Lake Moraine, whose altitude was 10,200 feet, or only 1,600 feet lower than Corona, is about the same as at the much lower stations, Green River and Lakin; the magnitude of obscuration was 0.99 at Lake Moraine. From Fig. 2, it will be seen that Green River, Corona, Lake Moraine, and Lakin, are all in the same general locality. This difference in the topographical surroundings of Corona and Lake Moraine may be noted however: Corona is practically on the summit of the mountain chain on which it is situated, whereas Lake Moraine is down in a pocket, completely surrounded by higher peaks, one of which is Pikes Peak (altitude 14,108 feet). The increased effects at Corona may perhaps indicate that the primary currents to which the effects are to be attributed circulated at a lower height, relatively, at the Corona station than at the other stations.

46. It may also be pointed out that the Corona curve in other notable features does not occupy an intermediate position between the curves at Green River and Lakin, as might have been concluded that it should owing to its intermediate position in the belt of totality. It in fact resembles most closely the curves at Sitka and Meanook (see Fig. 10). Thus at $20^h\ 30^m$ at Sitka, Meanook, and Corona there is a trough which is delayed about 15 minutes at Green River, Lake Moraine, and Lakin. Later we may be able to determine the precise causes for the interesting departures of the Corona curve from those of the neighboring stations. In the meanwhile we must content ourselves with the mere statement of the following fact: *The magnetic effects during the period of observation were considerably intensified and somewhat displaced in time, by some cause, at the exposed mountain-station, Corona, Colorado, whose altitude above sea-level was about 11,800 feet.*

47. The light lines connect the salient points of the curves, designated as stated in paragraph 41. Examining first the curves,

Honolulu to Porto Rico, it will be seen that the lines through the points *a*, *B*, and *c* have but little convergence, the effects occurring at the various stations at nearly the same average time. Beginning with crest *D*, however, and continuing to the trough *g′*, the lines have a general tendency towards the lower right hand corner of the diagram, i. e., the times at which the corresponding features (salient points) occur are, in general, later as we advance towards easterly stations. This progression in the times is especially noticeable during the periods when the eclipse occurs at the different stations. The lines through the points *F* and *g* follow closely a line supposedly drawn through the points (times) at which the middle of the eclipse occurred, as indicated by the heavy bars. The effects travel slowest from station to station during the local eclipse-interval. The preliminary effects, *a*, *B*, *c*, *D* occur either at nearly the same time or travel very rapidly eastward, or westward, as the case may be. Similarly the crest *H*, which occurred after the local eclipse-period, traveled rapidly, the general tendency being westward.

48. Since the eclipse began on the Earth at $19^h\ 29^m$ and ended at $24^h\ 46^m$, we may say for the stations Honolulu to Porto Rico, that shortly after the eclipse began there was a downward movement in all the curves, which means a westerly progression of the declination-needle. Near the ending of the eclipse, there was at these stations, on the other hand, an upward movement of the curves, or an easterly progression of the needle. For the stations west of Honolulu (Kakioka, Lukiapang, Antipolo, and also at Watheroo), the effects appear to have been, in general, the reverse of those just described. (See Figs. 9 and 10, and Table 11*a*.)

49. The dividing line between the regions of direct and reversed motions of the declination-needle appears to be approximately a north and south line between meridian 160° West and the meridian which passes through the place where the central eclipse occurred at local apparent noon, viz., longitude 152° 10′ West and latitude 50° 51′ North; this point, which we will call *M*, is in the highest northerly latitude reached by the central line of the totality belt. From the point of beginning of the central eclipse to the point *M*, the shadow cone had been moving to the east and to the north; at *M* the motion in latitude is reversed and thereafter the shadow-cone moved southerly during its continued eastwardly course. The point *M* also marks the instant, $22^h\ 07^m$, Greenwich civil mean time, June 8, when the shadow cone had

passed over one-half of its total path, or the mid-point between the beginning and ending of the eclipse on the Earth. We may, accordingly, draw the following tentative conclusion: *The motion of the declination-needle at stations approximately in the second half of the zone of visibility of the eclipse of June 8, 1918, at the same absolute time, was, in general, the reverse of that at stations approximately in the first half of the zone. In brief, a meridian of about 160° West may possibly be regarded as a sufficient approximation to the magnetic equator of the system of forces which gave rise to the magnetic effects during the eclipse of June 8, 1918. This matter will receive further consideration later.*

50. The Greenwich civil mean times at which the various salient points occur at the different stations for which we have declination data, are given in Tables 11 and 11*a*.

TABLE 11.—*Greenwich mean times of chief salient points of △D-curves (Figs. 9 and 10) at Honolulu and easterly stations for June 8, 1918.*

No.	Station	a	B	c	D	e	F	g	H	Eclipse Circumstances			
		h 19	h 20	h 20	h 21	h 21	h 22	h 23	h 24	Beg.	Mid.	End	Mag.
		m	m	m	m	m	m	m	m	h m	h m	h m	
18	Honolulu	35	20	30	03	10	−35	−50	45	21 01	21 45	22 30	0.09
19	Sitka	52	20	30	07	*32*	32	18	13	21 13	22 27	23 40	0.75
8	Berkeley	35	−5	*43*	05	*46*	72	30	20	21 49	23 10	24 22	0.79
1	Goldendale	45	10	38	08	*45*	85	45	14	21 41	23 00	24 12	1.01
20	Meanook	35	12	30	05	47	*63*	48	15	21 44	22 54	23 59	0.75
2	Green River	47	12	45	13	54	*76*	*50*	30	22 04	23 18	24 24	1.01
3	Corona	49	05	27	14	55	*75*	*48*	34	22 11	23 23	24 27	1.01
9	Lake Moraine	45	17	42	17	60	*85*	*48*	32	22 14	23 25	24 28	0.99
4	Lakin	*37*	*13*	47	*17*	62	78	58	35	22 18	23 28	24 30	1.01
21	Tucson	40	*17*	45	19	62	80	42	30	22 15	23 30	24 34	0.76
9b	Columbia	....	10	45	09	*70*	*68*	*40*	*25*	22 25	23 29	24 28	0.89
9a	Urbana	....	....	....	....	*67*	*80*	45	30	22 26	23 28	24 25	0.83
5	Mena	40	20	45	12	67	75	*50*	32	22 34	23 35	24 34	1.01
6	Brewton	30	15	45	22	*82*	95	55	35	22 38	23 40	24 36	1.01
10	Austin	....	*25*	43	*17*	*95*	90	40	45	22 34	23 40	24 39	0.87
7	Orlando	40	25	43	*33*	*95*	*80*	45	[35]	22 43	23 42	a.s.s.	1.00
22	Agincourt	35	14	39	09	*85*	100	55	24	22 27	23 23	24 15	0.68
11	Washington	32	15	*40*	10	*105*	110	55	40	22 33	23 29	24 21	0.74
23	Cheltenham	37	15	42	09	*120*	110	55	35	22 33	23 29	24 21	0.74
12	Woburn	*30*	15	35	10	*92*	95	55	30	22 31	23 23	24 12	0.63
13	Rivière	*35*	14	32	10	*92*	97	55	05	22 29	23 16	24 03	0.52
24	Porto Rico	....	32	45	16	150	....	....	30	out-	side	zone	.....

TABLE 11a.—*Greenwich mean times of chief salient points of* $\triangle D$-*curves* (*Figs. 9 and 10*) *at Kakioka and westerly stations for June 8, 1918.*

No.	Station	N	o	P	q	R	s	T	Eclipse Circumstances			
		h 19	h 20	h 20	h 21	h 21	h 23	h 24	Beg.	Mid.	End	Mag.
		m	m	m	m	m	m	m	h m	h m	h m	
25	Watheroo	35	12	42	08	58	60	*40*	out-	side	zone	.....
15	Antipolo	30	10	55	10	55	57	40	out-	side	zone	.....
14	Lukiapang	38	05	40	05	55	60	60+	.....	20 54	21 34	0.69
16	Kakioka	35	12	45	03	55	55	28	19 46	20 41	21 42	0.88

51. Collecting the weighted mean results as derived from Table 12, we obtain the following quantities:

Groups	$H\triangle D$						$H^2\triangle D$					
	Terr. Ecl. Int.			Loc. Ecl. Int.			Terr. Ecl. Int.			Loc. Ecl. Int.		
	Av. Effect		Max. Range	Av. Effect		Max. Range	Av. Effect		Max. Range	Av. Effect		Max. Range
	without sign	with sign		without sign	with sign		without sign	with sign		without sign	with sign	
	γ	γ	γ	γ	γ	γ	γ	γ	γ	γ	γ	γ
Group I (Totality Belt).....	4.31	0.00	17.6	3.73	+1.03	11.2	1.00	+0.01	4.1	0.85	+0.23	2.6
Groups II & III (Outside Belt)	4.63	—0.73	18.1	3.72	+0.01	10.1	1.01	—0.12	2.9	0.79	+0.02	2.1
Stations North of Belt......	4.70	—1.12	20.7	3.28	—0.38	10.4	0.86	—0.21	2.8	0.61	—0.08	2.0
Stations South of Belt......	4.53	—0.15	14.8	4.73	+0.90	9.1	1.24	+0.02	3.0	1.21	+0.24	2.3

It will be seen that the results are not materially different for the four different groupings, as far as the quantities for the terrestrial eclipse-interval are concerned. For the local eclipse-interval, however, there is some slight indication that the average effect, regardless of sign, is largest for the mean of stations south of the belt of totality. Looking over the $H^2\triangle D$-quantities in Table 12, they appear to show, in general, less variation from station to station than the $H\triangle D$-quantities, the reason for which will be made evident in paragraph 74.

TABLE 12.—*Average declination effects and maximum ranges for June 8, 1918.*

Group	No.	Station	ΔD						HΔD						H²ΔD						p
			Terr. Ecl. Int.			Loc. Ecl. Int.			Terr. Ecl. Int.			Loc. Ecl. Int.			Terr. Ecl. Int.			Loc. Ecl. Int.			
			Av. Effect		Max. Range	Av. Effect		Max. Range	Av. Effect		Max. Range	Av. Effect		Max. Range	Av. Effect		Max. Range	Av. Effect		Max. Range	
			without sign	with sign		without sign	with sign		without sign	with sign		without sign	with sign		without sign	with sign		without sign	with sign		
			′	′	′	′	′	′	γ	γ	γ	γ	γ	γ	γ	γ	γ	γ	γ	γ	
I	1	Goldendale	1.3	—1.32	3.0	1.0	—1.00	2.2	7.7	—7.7	17.5	5.8	—5.8	12.8	1.5	—1.5	3.5	1.2	—1.2	2.6	0.5
	2	Green River	0.4	+0.08	2.0	0.3	+0.09	1.6	2.3	+0.5	12.4	1.8	+0.6	9.9	0.5	+0.1	2.6	0.4	+0.1	2.1	0.5
	3	Corona	1.0	+0.68	3.6	1.1	+1.11	2.1	6.7	+4.4	23.2	7.3	+7.2	13.6	1.5	+1.0	5.2	1.6	+1.6	3.0	1.0
	4	Lakin	0.4	+0.34	2.0	0.4	+0.34	1.6	2.9	+2.2	13.1	2.5	+2.2	10.4	0.7	+0.5	3.0	0.6	+0.5	2.4	1.0
	5	Mena	0.5	—0.20	2.3	0.4	—0.29	1.1	3.2	—1.4	16.3	2.8	—2.1	7.7	0.8	—0.3	4.0	0.7	—0.5	1.9	1.0
	6	Brewton	0.5	—0.20	2.6	0.4	—0.08	1.8	3.7	—1.5	19.0	2.5	—0.6	13.2	0.9	—0.4	4.8	0.6	—0.2	3.3	1.0
	7	Orlando[1]	[0.6]	[—0.02]	[2.6]	[0.4]	[+0.40]	[1.4]	[4.4]	[—0.2]	[20.0]	[3.2]	[+3.1]	[10.8]	[1.2]	[—0.1]	[5.3]	[0.8]	[+0.8]	2.9	0.5
	Weighted Means (Group I).....		.....	.....	.....	.....	.....	.....	4.31	0.00	17.6	3.73	+1.03	11.2	1.00	+0.01	4.1	0.85	+0.23	2.6	.....
II	8	Berkeley[2]	2.5	—2.47	3.5	1.6	—1.63	2.5	18.1	—18.1	25.5	11.8	—11.8	18.2	4.5	—4.5	6.3	3.0	—3.0	4.5	0.5
	9	Lake Moraine	0.5	—0.01	2.4	0.5	+0.42	1.6	3.4	—0.1	15.5	3.0	+2.7	10.3	0.8	0.0	3.5	0.7	+0.6	2.3	0.5
	9a	Urbana[3]	[1.3]	[—0.06]	[5.1]	0.9	+0.30	3.9	[7.5]	[—0.3]	[28.9]	4.9	+1.7	22.1	[1.5]	[—0.1]	[5.6]	1.0	+0.3	4.3	0.5
	9b	Columbia[4]	[0.7]	[+0.23]	[3.6]	0.3	—0.28	0.9	[4.2]	[+1.4]	[22.1]	2.0	—1.7	5.5	[0.9]	[+0.3]	[4.7]	0.4	—0.4	1.2	0.5
	10	Austin	0.3	+0.08	1.1	0.3	+0.16	1.0	2.2	+0.6	8.6	2.3	+1.2	7.8	0.6	+0.2	2.3	0.6	+0.3	2.1	0.5
	11	Washington	0.7	—0.19	3.6	0.5	+0.25	1.5	3.9	—1.0	19.7	2.5	+1.4	8.2	0.7	—0.2	3.7	0.5	+0.3	1.5	0.5
	12	Woburn	2.0	—1.92	4.9	2.4	—2.33	3.0	9.8	—9.5	24.2	11.7	—11.5	14.8	1.7	—1.6	4.1	2.0	—2.0	2.5	0.5
	13	Rivière du Loup	2.0	+1.92	8.3	0.8	+0.75	1.7	8.2	+7.8	33.7	3.1	+3.1	6.9	1.1	+1.1	4.7	0.4	+0.4	1.0	0.5
	Weighted Means (Group II).....		.....	.....	.....	.....	.....	.....	7.16	—2.40	22.3	5.16	—1.86	11.7	1.48	—0.60	4.4	1.08	—0.44	2.4	.....
III	25	Watheroo	1.5	+0.09	1.1	.....	.....	.....	1.1	+0.7	8.0	.....	.....	.....	0.3	+0.2	2.0	.....	.....	.....	0.5
	15	Antipolo	0.3	+0.03	1.4	.....	.....	.....	3.6	+0.3	15.6	.....	.....	.....	1.4	+0.1	5.9	.....	.....	.....	0.5
	14	Lukiapang	0.3	—0.04	1.5	0.2	+0.09	0.7	2.6	—0.4	14.5	1.7	+0.9	6.8	0.9	—0.1	4.8	0.6	+0.3	2.3	0.5
	16	Kakioka	0.4	—0.02	2.2	0.3	—0.02	1.2	3.1	—0.2	19.0	2.3	—0.2	10.3	0.9	—0.1	5.6	0.7	—0.1	3.1	1.0
	18	Honolulu	0.4	+0.20	2.0	0.1	+0.04	0.5	3.2	+1.7	16.8	1.2	+0.3	4.2	0.9	+0.5	4.9	0.3	+0.1	1.2	1.0
	19	Sitka	0.8	—0.61	4.0	0.5	—0.33	2.1	3.6	—2.8	18.1	2.4	—1.5	9.5	0.6	—0.4	2.8	0.4	—0.2	1.5	1.0
	20	Meanook	1.5	—0.43	5.9	1.2	+0.62	4.7	5.6	—1.6	22.1	4.5	+2.3	17.6	0.7	—0.2	2.9	0.6	+0.3	2.3	1.0
	21	Tucson	0.5	+0.43	1.7	0.9	+0.87	1.2	4.1	+3.4	13.3	6.8	+6.8	9.4	1.1	+0.9	3.6	1.8	+1.8	2.5	1.0
	22	Agincourt	0.7	—0.22	3.5	0.5	—0.03	1.9	3.2	—1.0	16.1	2.4	—0.1	8.8	0.5	—0.2	2.6	0.4	0.0	1.4	1.0
	23	Cheltenham	0.7	—0.43	3.4	0.3	—0.09	0.9	4.0	—2.4	19.1	1.7	—0.5	5.0	0.8	—0.5	3.7	0.3	—0.1	1.0	1.0
	24	Porto Rico	0.4	+0.30	1.8	.....	.....	.....	3.4	+2.4	14.7	.....	.....	.....	1.0	+0.7	4.1	.....	.....	.....	1.0
	Weighted Means (Group III)....		.....	.....	.....	.....	.....	.....	3.56	—0.02	16.7	2.95	+1.01	9.1	0.82	+0.08	2.3	0.64	+0.26	1.9	.....

[1]Observations ended at 24h 15m.
[2]Observations somewhat affected by electric train effects.
[3]Observations began at 21h 45m.
[4]Observations began at 20h.

Horizontal-Intensity Data.

52. The present horizontal-intensity data are confined to the following stations: Goldendale and Lakin, inside the belt of totality; Lukiapang, Kakioka, Honolulu, Sitka, Tucson, Agincourt, and Cheltenham, outside of the belt but within the zone of visibility of the eclipse; Antipolo, just west of the western limit of the zone of visibility, and Porto Rico, just east of the eastern limit of the zone. *The five-minute values of the horizontal intensity, H, are plotted in Fig. 11, an upward movement of the curves denoting increased H.* The diagram, in view of the explanations given for previous ones (Fig. 7, paragraph 24), will require no further remark. The data have already been published in the previous issue of *Terrestrial Magnetism*, except those for Goldendale and Lakin. The curve is broken for Lukiapang as it depends upon scalings from the magnetogram received for which no data for possible temperature corrections were supplied.

53. *Horizontal-intensity changes at Goldendale, Washington, June 8, 1918.* The instrument (C. I. W. magnetometer No. 26) was installed in the blockhouse (station C), as described in *Terrestrial Magnetism*, Sept., 1918, pages 99-100. The deflecting magnet was placed on the deflection bar at the distance of 20 cm. east of deflected magnet, north end being east. The instrument was next turned so that the magnet appeared centrally on the scale and it was then clamped firmly in position. Readings of declination were made with C. I. W. magnetometer No. 13 at an outside station, A, simultaneously with the readings of magnetometer No. 26. The temperature was read on the thermometer mounted so that the bulb was in contact with the deflecting magnet, the stem projecting through the protecting housing; readings were made every minute. As the instrument was mounted, an increase in the scale reading, if the magnetic declination and temperature remained the same, indicated an increase in H. An increase in temperature caused an increase in the scale-reading, and an increase, $+\triangle D$, in east declination produced a decrease in the scale-reading. The following formula was used for determining $\triangle H$ from the observed scale readings:

$$\triangle H=[(20-s)e-(26^\circ-t)q-\triangle D]k$$

in which

s = scale-reading

$e = 1'.97$, the scale value for magnetometer No. 26

t = temperature in degrees centigrade

$q = 0'.753$, the effect in minutes on the deflection angle for a change of 1° C

$\triangle D$ = change in east declination expressed in minutes

$k = -13.2\gamma$, the change in H represented by an increase of 1′ in the deflection angle u, for $u = 24°$ (approx.).

$\triangle D$ was taken somewhat arbitrarily, viz., $(23° 20' - D)$, in which D was the observed declination at station A at the time of the corresponding scale-reading of magnetometer No. 26.

The absolute value of H for the station C was not determined, but was approximated from the work done at adjacent stations with the aid of the formula $H = 20100\gamma + \triangle H$. The resulting values of H are given in Table 13.

TABLE 13.—*Values of horizontal intensity* (H) *at Goldendale, June 8, 1918.*
[$H = 20000\gamma$ + tabular value.]

G.M.T.	19^h	20^h	21^h	22^h	23^h	24^h	G.M.T.	19^h	20^h	21^h	22^h	23^h	24^h
m	γ	γ	γ	γ	γ	γ	m	γ	γ	γ	γ	γ	γ
0	....	76	93	101	91	86	30	81	99	94	94	91	90
5	....	78	93	99	89	87	35	82	103	94	97	93	89
10	....	77	98	95	89	88	40	81	103	97	98	92	91
15	75	81	93	96	88	86	45	77	103	102	96	88	88
20	72	88	98	94	90	91	50	78	98	102	95	86	86
25	78	93	97	95	91	88	55	76	96	102	93	86	82
30	81	99	94	94	91	90	60	76	93	101	91	86	86

54. *Magnetograph results at Lakin, Kansas, June, 1918.* Self-registering variometers for all three elements were operated from June 5 to June 26 by D. M. Wise of the Department of Terrestrial Magnetism at a point within the belt of totality in western Kansas, about 3½ miles south and 2½ miles west of Lakin, a station on the Santa Fe railroad. Figure 5 shows the small house in which the instruments were mounted, and the tent station, about 30 meters nearly east of the southeast corner of the house, where the absolute determinations, as well as the eye-readings of declination during the eclipse of June 8, were made. Fig. 6, page 103, shows the instruments installed in the southeast corner room of the house. This room was darkened and insulated as completely as possible by use of tarred building-paper, the entrance being through rooms adjoining on the north. The *instruments* were as follows:

Declination variometer No. 5, made in the shops of the Department, with registering apparatus No. 3, made by Toepfer and Son;
Horizontal-intensity variometer, with registering apparatus No. 5, both made by the Department;

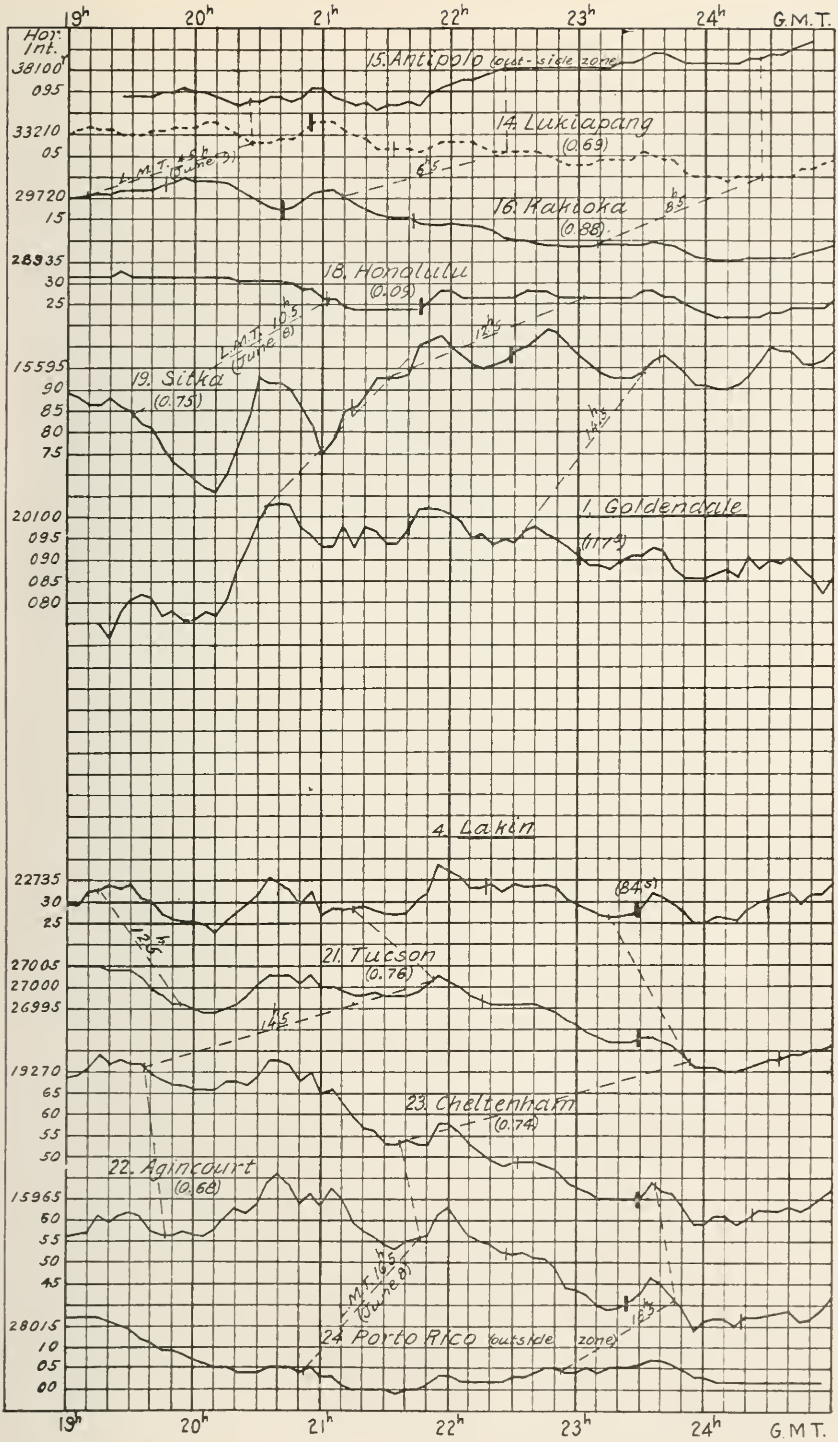

Fig. 11.—Horizontal-Intensity Curves, Solar Eclipse, June 8, 1918.

Eschenhagen vertical-intensity variometer No. 21 of the United States Coast and Geodetic Survey, loaned to the Department for the occasion and mounted so as to record on apparatus No. 5 simultaneously with the horizontal intensity.

On account of delay in receiving lenses ordered for these variometers, others of different focal lengths were substituted, and it was found that the three instruments could not be made to record on the same drum without mutual disturbing effect. This made it necessary to use the two registers mentioned in the above list of instruments. Portions of the floor were removed and wooden pillars were set firmly in the ground to support the instruments, the openings around the supports being carefully covered with tarred building-paper to shut out air-currents and to improve the insulation. The *scale value and iemperature coefficient* for each of the instruments were as follows:

Element	*Scale Value*	*Temperature Coefficient*
Declination	1mm. = 1′.184	....
Horizontal Intensity	1mm. = 1γ.93	−12γ.6 per 1° C.
Vertical Intensity	1mm. = 5.12	−2.26 per 1° C.

In the temperature curve, 1 mm. of ordinate represented a change of 0°.0593 C. In the region where Lakin is situated, temperature changes from day to night hours were quite large, with the result that in the variation-room the average daily range was about 5° C., though on extreme days it reached 10° C. Fortunately on the early days of June, particularly the 7th and 8th, the range was less than 3° C.

55. Absolute observations for the determination of the *Lakin base-line values* were made on 9 days between June 5 and 26. The changes in the base-lines, particularly in the earlier days of the month, were found to be large, though in the case of the declination the drift was sufficiently uniform to permit drawing a smooth curve through the plotted values, from which interpolations were readily made. The declination base-line varied from 11° 40′.4 on June 5, to 11° 35′.2 on June 14. The horizontal intensity base-line varied much more irregularly. The values adopted for the days involved in the discussion of the solar-eclipse effects were interpolated between the absolute determinations on June 7 and June 9. The rate of the drift altered suddenly between these dates, the time and amount of the change being deduced from a comparison with the hourly values covering the period obtained from the observatories at Cheltenham and Tucson, supplied by the United States Coast and Geodetic Survey. The values adopted

were as follows, linear interpolations being made for intermediate times: June 7, $17^{h}.2$ G. M. T., 22753γ; June 8, $19^{h}.2$ G. M. T., 22760γ; June 9, $7^{h}.0$ G. M. T., 22690γ; these values refer to temperature 25° C. The vertical intensity base-line varied from 53556γ on June 7 at $21^{h}.8$ G. M. T., to 53524γ on June 9 at $20^{h}.7$ G. M. T., linear interpolations being made for intermediate times. While values of magnetic elements obtained by means of variometers which have not yet settled down to a more or less permanent state, must be subject to considerable error, it is not thought probable that the characteristic features of any one of the Lakin curves will require any serious modification, since only comparatively short intervals of time are involved.

56. Tables 14 and 15 contain, respectively, for June 7 and 8, magnetograph values of D, H, and Z, for every five minutes, as also the temperatures. The values of D already given in Table 3, page 107, are the results of the magnetometer eye-readings in the tent. Table 16 contains some supplementary values for June 7, 8, and 9.

TABLE 16.—*Supplementary magnetograph values of magnetic elements and temperature at Lakin, Kansas, June 7, 8, and 9, 1918.*

[D = 12°E + tabular value; H = 22700γ + tabular value; Z = 53300γ + tabular value.]

G.M.T.	June 7, 1918				June 8, 1918				G.M.T.	June 8, 1918				June 9, 1918			
	D	H	Z	Temp.	D	H	Z	Temp.		D	H	Z	Temp.	D	H	Z	Temp.
h m	′	γ	γ	°C	′	γ	γ	°C	h m	′	γ	γ	°C	′	γ	γ	°C
17 00	30.1	01	96	20.2	30.3	12	75	20.3	1 00	30.0	18	123	20.5	30.8	34	97	22.7
05	....	....	....	....	....	....	....	....	05	....	18	123	20.5	....	36	96	22.6
10	29.8	05	94	20.3	29.9	08	73	20.4	10	30.1	19	123	20.5	30.4	38	96	22.6
15	....	....	....	....	....	....	....	....	15	....	20	122	20.4	....	38	95	22.6
20	29.3	08	94	20.3	29.3	14	74	20.5	20	30.2	22	121	20.4	30.2	36	94	22.5
25	....	....	....	....	....	....	....	....	25	....	23	121	20.4	....	36	94	22.5
30	28.5	07	94	20.3	28.6	22	74	20.6	30	30.2	24	121	20.4	30.2	36	93	22.5
35	....	....	....	....	....	....	....	....	35	....	27	120	20.3	....	35	93	22.5
40	28.0	06	93	20.4	27.9	20	75	20.7	40	29 9	26	120	20.3	30.1	[36]	92	22.5
45	....	....	....	....	....	....	....	....	45	....	25	118	20.3	....	37	93	22.4
50	27.3	07	94	20.4	27.4	20	74	20.8	50	29.6	25	118	20.3	29.8	37	94	22.5
55	....	....	....	....	....	....	....	....	55	....	23	118	20.2	....	37	91	22.5
18 00	26.7	11	96	20.3	27.1	21	74	20.9	2 00	29.3	22	117	20.2	29.6	37	92	22.5
05	....	12	96	20.3	....	21	74	20.9	05	....	....	....	....	....	....	....	....
10	26.2	13	97	20.2	26.9	25	74	20.9	10	29.6	22	115	20.2	29.6	35	92	22.5
15	....	14	97	20.2	....	26	74	20.9	15	....	....	....	....	....	....	....	....
20	25.7	14	98	20.1	26.6	25	74	20.9	20	30.1	22	115	20.2	29.8	36	93	22.5
25	....	12	98	20.0	....	23	74	20.9	25	....	....	....	....	....	....	....	....
30	25.4	14	98	19.9	26.4	20	74	20.9	30	30.1	21	115	20.2	29.9	37	92	22.5
35	....	14	95	19.9	....	17	74	21.0	35	....	....	....	....	....	....	....	....
40	25.0	14	96	19.9	26.0	22	73	21.0	40	29.2	22	114	20.2	29.5	35	91	22.5
45	....	16	97	19.9	....	28	73	21.0	45	....	....	....	....	....	....	....	....
50	25.2	16	98	20.0	25.8	27	74	21.1	50	29.5	21	113	20.1	29.4	37	91	22.5
55	....	18	100	20.0	....	29	73	21.1	55	....	....	....	....	....	....	....	....
19 00	25.3	20	101	20.1	25.6	29	74	21.2	3 00	29.9	21	113	20.1	29.3	39	91	22.5

TABLE 14.—*Magnetograph values of magnetic elements and temperature at Lakin, Kansas, June 7, 1918.*

[D = 12°E + tabular value; H = 22700γ + tabular value; Z = 53300γ + tabular value.]

G.M.T.	D	H	Z	Temp.	G.M.T.	D	H	Z	Temp.
h m	′	γ	γ	°C	h m	′	γ	γ	°C
19 00	25.3	20	101	20.1	22 00	27.0	25	112	20.8
05	25.3	21	102	20.1	05	27.1	25	112	20.8
10	25.3	23	102	20.2	10	27.2	24	112	20.8
15	25.2	24	102	20.2	15	27.5	24	112	20.8
20	25.3	25	102	20.3	20	27.6	23	113	20.8
25	25.2	26	101	20.3	25	27.7	22	113	20.8
30	25.1	26	101	20.4	30	27.8	22	114	20.8
35	24.9	27	101	20.4	35	27.9	23	115	20.8
40	24.8	27	100	20.5	40	27.9	23	116	20.8
45	24.8	28	100	20.5	45	28.1	24	118	20.8
50	24.8	28	100	20.5	50	28.3	23	119	20.8
55	24.7	29	98	20.6	55	28.3	23	119	20.8
20 00	24.6	29	97	20.6	23 00	28.5	22	119	20.8
05	24.7	29	96	20.6	05	28.5	21	119	20.8
10	24.9	28	96	20.7	10	28.5	20	118	20.9
15	24.9	28	96	20.7	15	28.6	21	119	20.9
20	24.9	28	96	20.7	20	28.9	21	120	20.9
25	25.0	26	96	20.8	25	29.1	18	121	20.9
30	25.3	24	97	20.8	30	29.1	17	121	20.9
35	25.4	24	98	20.9	35	29.2	20	122	20.9
40	25.6	25	98	20.9	40	29.3	22	123	20.9
45	25.6	26	98	20.9	45	29.7	28	124	20.9
50	25.7	26	98	20.9	50	30.2	30	127	20.8
55	25.7	28	99	20.9	55	30.4	30	128	20.8
21 00	25.7	28	100	20.9	24 00	30.6	28	129	20.8
05	25.7	28	102	20.9	05	30.4	26	129	20.8
10	25.8	27	104	20.9	10	30.5	22	130	20.8
15	26.0	26	105	20.9	15	30.4	18	130	20.7
20	26.1	24	107	20.9	20	30.3	16	130	20.7
25	26.0	23	108	20.9	25	30.1	15	129	20.7
30	26.1	24	108	20.9	30	30.1	13	127	20.7
35	26.1	24	109	20.9	35	30.0	12	127	20.6
40	26.3	25	111	20.9	40	30.0	15	126	20.6
45	26.5	25	110	20.8	45	30.2	16	126	20.6
50	26.8	25	111	20.8	50	30.2	14	125	20.6
55	26.9	25	111	20.8	55	30.1	15	124	20.6
					25 00	30.0	18	123	20.5

TABLE 15.—*Magnetograph values of magnetic elements and temperature at Lakin, Kansas, June 8, 1918.*

[D = 12°E + tabular value; H = 22700γ + tabular value; Z = 53300γ + tabular value.]

G.M.T.	D	H	Z	Temp.	G.M.T.	D	H	Z	Temp.
h m	′	γ	γ	°C	h m	′	γ	γ	°C
19 00	25.6	29	74	21.2	22 00	26.6	38	90	22.9
05	25.4	29	73	21.3	05	26.8	36	90	23.0
10	25.3	33	74	21.4	10	27.0	33	90	23.0
15	25.2	33	74	21.5	15	27.3	34	90	23.1
20	24.8	34	75	21.6	20	27.3	34	90	23.2
25	24.8	33	75	21.6	25	27.6	32	91	23.1
30	24.7	35	75	21.7	30	27.6	34	90	23.2
35	24.6	31	76	21.8	35	27.8	34	90	23.2
40	24.7	30	76	21.8	40	27.9	34	89	23.2
45	24.7	27	75	21.9	45	28.2	34	89	23.2
50	24.8	26	75	21.9	50	28.3	33	90	23.2
55	25.3	26	76	22.0	55	28.4	30	90	23.3
20 00	25.4	25	76	22.0	23 00	28.6	29	91	23.4
05	25.8	25	79	22.1	05	28.7	28	91	23.4
10	25.9	22	78	22.2	10	29.0	27	92	23.4
15	25.9	26	79	22.3	15	29.3	26	92	23.4
20	25.9	28	80	22.3	20	29.4	26	92	23.4
25	25.7	30	82	22.4	25	29.6	27	94	23.4
30	25.5	32	82	22.4	30	29.6	28	95	23.3
35	25.4	36	83	22.5	35	29.7	32	95	23.3
40	25.4	35	83	22.6	40	29.8	31	95	23.3
45	25.2	33	83	22.6	45	30.0	30	96	23.3
50	25.4	30	85	22.6	50	30.4	28	97	23.3
55	25.4	33	84	22.6	55	30.5	25	98	23.3
21 00	25.8	27	84	22.7	24 00	30.6	25	98	23.2
05	26.2	28	85	22.7	05	30.7	27	98	23.2
10	26.4	28	84	22.7	10	31.0	26	99	23.2
15	26.5	29	85	22.8	15	31.1	26	98	23.1
20	26.4	29	86	22.9	20	31.1	28	97	23.1
25	26.5	28	86	22.9	25	31.3	30	98	23.1
30	26.6	27	88	22.9	30	31.4	31	100	23.0
35	26.6	27	90	22.9	35	31.4	32	99	23.0
40	26.8	28	89	22.9	40	31.4	32	99	22.9
45	26.8	31	90	22.9	45	31.3	30	98	22.9
50	26.9	32	90	22.9	50	31.0	32	98	22.8
55	26.5	38	90	22.9	55	30.8	32	97	22.7
					25 00	30.8	34	97	22.7

Vertical-Intensity Data.

57. Figure 12 gives the curves of vertical intensity as observed on June 8, 1918, at Antipolo, Lukiapang, Kakioka, Honolulu, Sitka, Lakin, Tucson, Cheltenham, Agincourt, and Porto Rico. The five-minute values at these stations will be found either in the present issue of *Terrestrial Magnetism* or in the previous one. It should be noted that for these curves *a downward movement means an increase in vertical intensity.*

In view of the difficulties frequently encountered in the registration of vertical-intensity effects, the data for the curves of Fig. 12 may not always possess the same reliability as did the declination curves (Figs. 7 and 8), or the horizontal-intensity curves (Fig. 11). The curve is broken for Lukiapang as it depends upon the scalings from the magnetogram received, for which no data for possible temperature corrections were supplied; there is also some uncertainty as to the precise scale value.

Discussion of Horizontal-Intensity Effects (△H-Curves).

58. In Fig. 13 are given the curves showing the $\triangle H$-quantities (Table 17), or horizontal-intensity effects obtained by subtracting from the observed values of H on June 8 the corresponding ones derived from the quiet days in June. For the normal values at the observatories of the Coast and Geodetic Survey, see previous issue of *Terrestrial Magnetism*, page 120, whereas for those of the Canadian observatories, see present issue, page 154. For Goldendale, data for the normal diurnal variation were deduced from those at Sitka and Tucson; the curve, accordingly, is broken. In the cases of Kakioka and Lakin, June 7 was taken as representing a sufficiently normal day for the present purposes. For Lukiapang and Antipolo the curves are broken, as the normal data were deduced from published observatory values pertaining to previous years. *The curves are plotted so that an upward movement means an increase in the horizontal intensity.* Attention should be called to the fact that the values of $\triangle H$, as given in Table 17, do not necessarily represent absolute magnetic effects to be associated with the eclipse; they are affected, of course, by any constant or variable difference in H between that of the mean normal day (taken as the mean of the quiet days) and that for June 8 had there been no eclipse. The absolute effect will be eliminated, more or less, in the differences of $\triangle H$, as, for example, when getting the range in the $\triangle H$-effect from a crest to a trough.

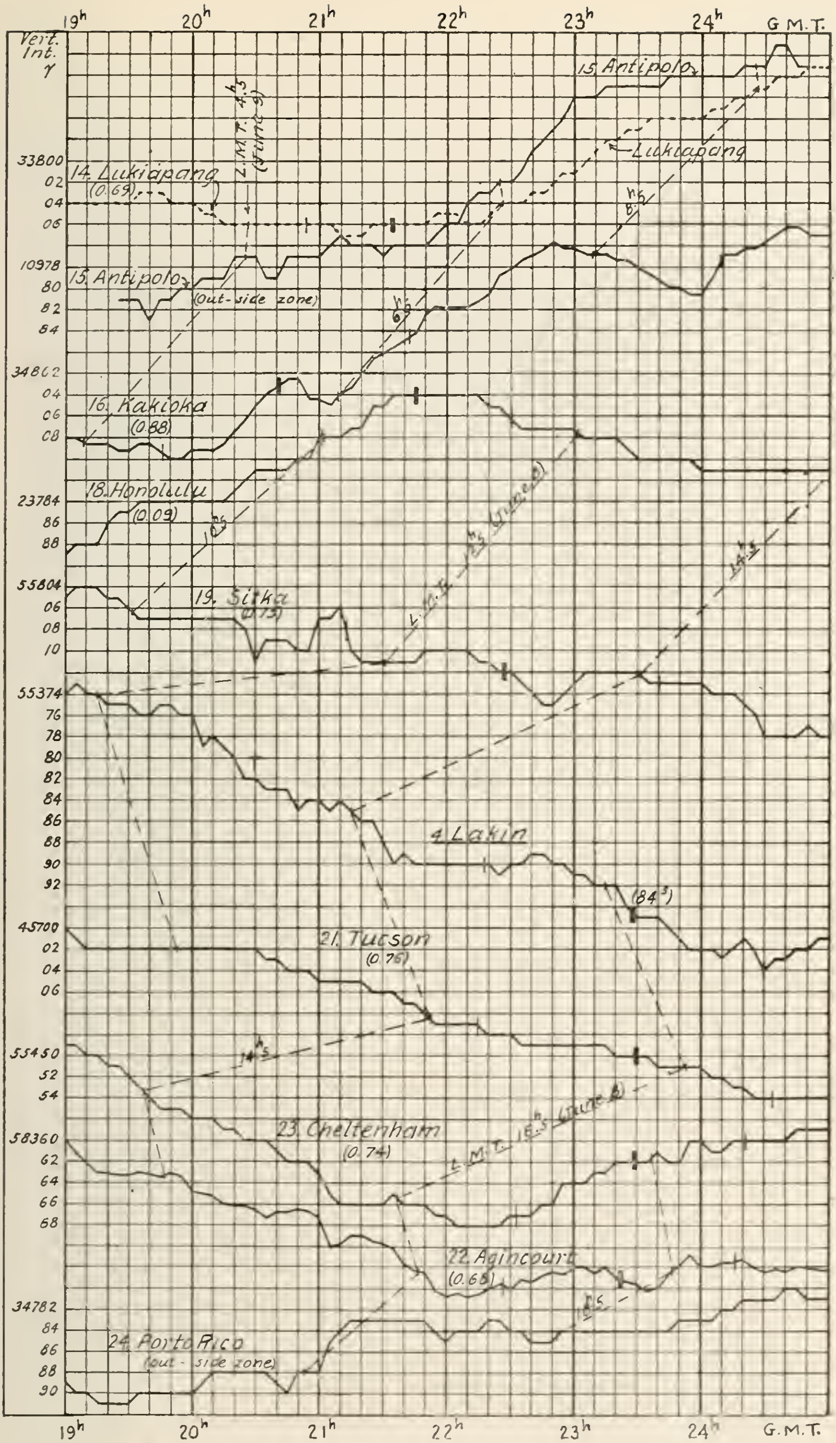

FIG. 12.—Vertical-Intensity Curves, Solar Eclipse, June 8, 1918.

59. *The effect on the horizontal intensity at Kakioka during the time of the eclipse* consists of a double wave as follows: A crest (increase of H) at about fifteen minutes after the beginning of the eclipse, followed by a trough (decrease of H) at time of maximum obscuration ($20^h\ 41^m$); next there is a crest again, indicating increase of H of about the same amount as for the first crest, at about 25 minutes after maximum obscuration; about 7 minutes before the end of the eclipse there is a secondary depression (decrease of H), followed by another rise at about $22^h\ 07^m$. The curve then descends gradually to a trough which occurs at about $23^h\ 52^m$; thereafter the curve ascends again and continues to do so for the balance of the interval of observation.

60. The *effects at the succeeding stations* during the eclipse are similar to those at Kakioka, though at times modified according to location of station and the preliminary effects. The Greenwich civil mean times when the chief salient features (points) of the $\triangle H$ curves occur at the various stations are practically the same as for the $\triangle X$-curves (see Table 23).

61. *Small preliminary effects.* Looking over the horizontal-intensity curves (Fig. 11), it will be noticed that near the beginning of the eclipse on the Earth, which occurred at $19^h 29^m$ G. M. T. as shown by the dotted line B, there is a small rise denoting a momentary increase in H. This small effect as shown on the $\triangle H$-curves (Fig. 13) is approximately as follows:

TABLE 18.—*Small preliminary magnetic effects, June 8, 1918.*

Station	G.M.T.	$\triangle H$	Station	G.M.T.	$\triangle H$
	h m	γ		h m	γ
Kakioka	19 25	+1	Tucson	19 30	+1
Honolulu	25	+1	Agincourt	*24*[1]	+3
Sitka	20	+2	Cheltenham	*30*[1]	+2
Goldendale	35	+4	Porto Rico	40	+1
Lakin	30	+2			
			Mean	19 28.2	+2

The vertical-intensity curves (Fig. 12) give some slight indication at about $19^h\ 30^m$ of a downward movement, which here means an increase in Z. This effect is shown best at Kakioka (see Fig. 14), and amounts to about 0.5γ.

There are also, apparently, some small preliminary effects shown on the declination curves (Figs. 9 and 10) at about the time noted above.

[1]Mean of three small crests from about $19^h\ 15^m$ to $19^h\ 35^m$.

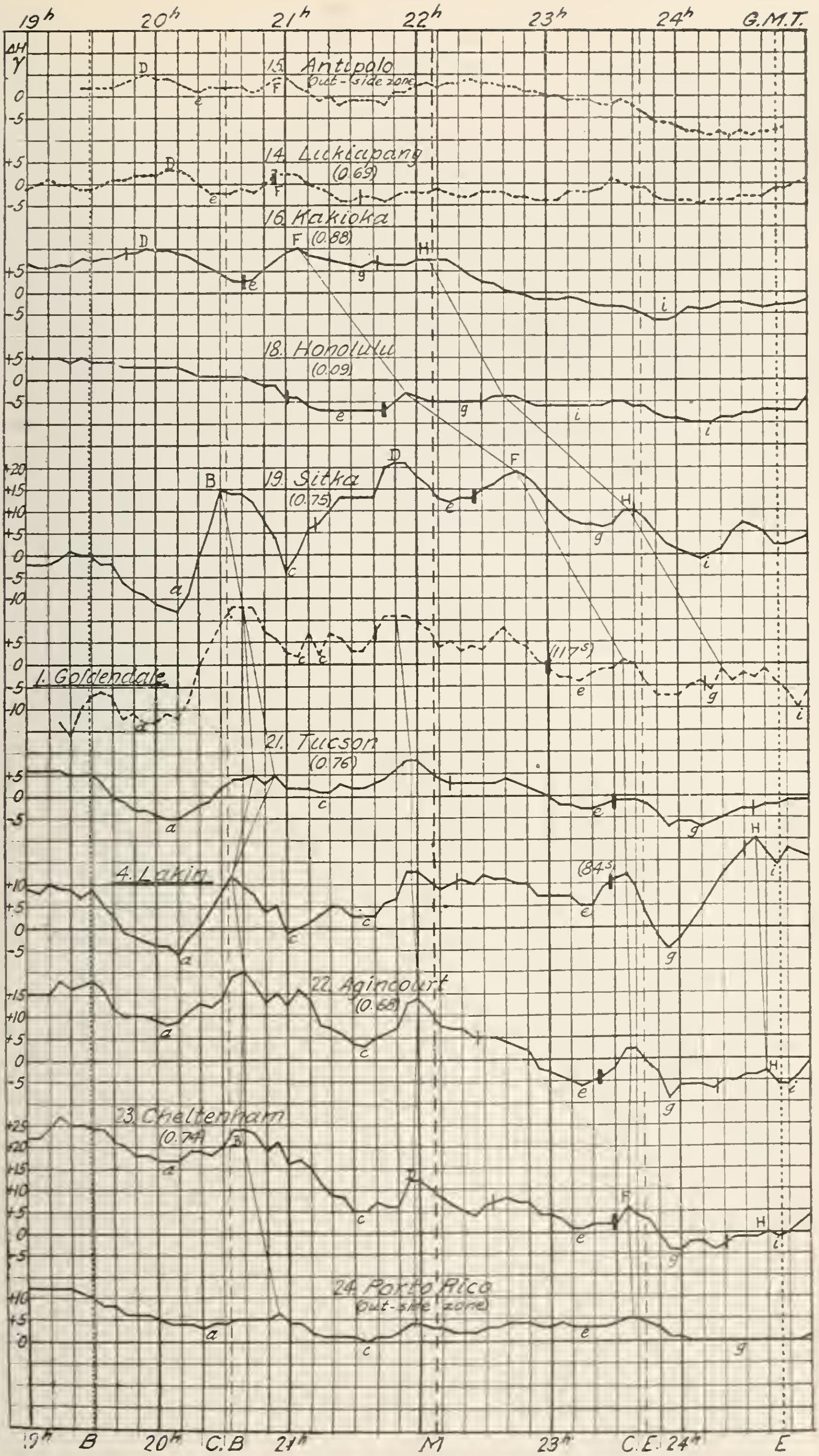

FIG. 13.— Δ H-Curves, Solar Eclipse, June 8, 1918.

TABLE 17.—*Five-minute values of △H for June 8, 1918.*

G.M.T.	Ant.	Luk.	Kak.	Hon.	Sit.	Gol.	Tuc.	Lak.	Agi.	Che.	P. R.
h m	γ	γ	γ	γ	γ	γ	γ	γ	γ	γ	γ
19 00	......	−1	+ 6.4	+ 5	− 2	....	+ 6	+ 9	+15	+22	+12
05	......	0	+ 5.9	+ 5	− 2	....	+ 6	+ 8	+15	+22	+12
10	......	+1	+ 5.9	+ 5	− 2	....	+ 6	+10	+15	+24	+12
15	......	0	+ 6.4	+ 5	− 1	−13	+ 6	+ 9	+18	+27	+12
20	......	0	+ 6.4	+ 4	+ 1	−16	+ 5	+ 9	+16	+25	+12
25	+2	−1	+ 8.0	+ 5	0	−10	+ 5	+ 7	+17	+25	+11
30	+2	−1	+ 7.4	+ 4	0	− 7	+ 5	+ 9	+18	+24	+10
35	+2	0	+ 8.0	+ 4	− 2	− 6	+ 3	+ 5	+16	+24	+ 8
40	+2	+1	+ 8.0	+ 4	− 2	− 7	0	+ 3	+12	+21	+ 8
45	+3	+1	+ 9.1	+ 3	− 6	−12	− 1	− 1	+10	+20	+ 6
50	+4	+2	+ 9.1	+ 3	− 8	−11	− 3	− 2	+10	+18	+ 6
55	+5	+2	+10.2	+ 3	− 9	−13	− 3	− 3	+10	+18	+ 6
20 00	+4	+2	+ 9.6	+ 3	−11	−13	− 4	− 4	+ 9	+17	+ 5
05	+4	+3	+ 9.6	+ 3	−12	−11	− 5	− 4	+ 8	+17	+ 4
10	+3	+3	+ 9.0	+ 3	−13	−12	− 5	− 6	+ 9	+17	+ 4
15	+2	+2	+ 8.5	+ 2	− 9	− 8	− 4	− 2	+11	+19	+ 4
20	+1	0	+ 6.9	+ 1	− 1	− 1	− 3	0	+13	+19	+ 3
25	+2	−2	+ 5.9	+ 1	+ 6	+ 4	− 1	+ 4	+12	+18	+ 4
30	+2	−2	+ 4.8	+ 1	+15	+ 9	+ 2	+ 8	+14	+20	+ 4
35	+2	−2	+ 3.2	+ 1	+14	+13	+ 4	+12	+19	+24	+ 5
40	+2	−1	+ 2.7	+ 1	+14	+13	+ 4	+10	+20	+24	+ 5
45	+1	−2	+ 3.2	0	+12	+13	+ 5	+ 7	+17	+23	+ 5
50	+2	0	+ 5.3	− 1	+ 8	+ 8	+ 3	+ 4	+13	+19	+ 5
55	+4	+2	+ 7.4	− 1	+ 4	+ 6	+ 5	+ 5	+15	+21	+ 6
21 00	+4	+2	+ 9.1	− 4	− 4	+ 3	+ 2	− 1	+12	+16	+ 4
05	+2	+2	+10.1	− 4	0	+ 2	+ 2	0	+16	+17	+ 4
10	+1	0	+ 8.6	− 6	+ 6	+ 7	+ 2	+ 1	+14	+15	+ 2
15	−1	−1	+ 8.0	− 7	+ 7	+ 2	+ 1	+ 3	+ 8	+11	+ 1
20	0	−2	+ 7.5	− 7	+10	+ 7	+ 1	+ 5	+ 7	+ 9	+ 1
25	−2	−4	+ 6.9	− 7	+13	+ 6	+ 3	+ 5	+ 6	+ 8	+ 1
30	−1	−4	+ 6.4	− 7	+13	+ 3	+ 2	+ 3	+ 4	+ 5	+ 1
35	−1	−3	+ 5.9	− 7	+13	+ 3	+ 2	+ 3	+ 3	+ 5	0
40	−1	−3	+ 7.0	− 7	+13	+ 6	+ 3	+ 3	+ 5	+ 7	+ 1
45	−2	−4	+ 6.4	− 7	+20	+11	+ 4	+ 6	+ 6	+ 6	+ 1
50	+1	−3	+ 6.4	− 5	+21	+11	+ 6	+ 7	+ 7	+ 6	+ 2
55	+1	−2	+ 6.4	− 3	+21	+11	+ 8	+13	+13	+12	+ 4
22 00	+2	−2	+ 7.5	− 4	+18	+10	+ 8	+13	+14	+12	+ 4
05	+3	−2	+ 7.5	− 5	+16	+ 8	+ 6	+11	+11	+10	+ 3
10	+2	−1	+ 7.5	− 5	+13	+ 4	+ 4	+ 9	+ 8	+ 8	+ 3
15	+3	−2	+ 7.4	− 5	+12	+ 5	+ 3	+10	+ 7	+ 6	+ 2
20	+3	−3	+ 5.9	− 5	+13	+ 3	+ 3	+11	+ 7	+ 5	+ 2
25	+4	−3	+ 3.8	− 5	+13	+ 4	+ 3	+10	+ 5	+ 4	+ 2
30	+3	−2	+ 2.6	− 5	+15	+ 3	+ 3	+12	+ 5	+ 6	+ 3
35	+3	−2	+ 2.1	− 4	+16	+ 6	+ 3	+11	+ 5	+ 7	+ 3
40	+2	−2	+ 0.5	− 4	+18	+ 7	+ 4	+11	+ 4	+ 8	+ 4
45	+2	−3	0.0	− 4	+19	+ 5	+ 3	+10	+ 3	+ 7	+ 4
50	+1	−3	− 0.5	− 5	+18	+ 4	+ 2	+10	+ 2	+ 7	+ 4
55	+1	−4	− 1.6	− 6	+16	+ 1	+ 1	+ 7	− 2	+ 4	+ 3
23 00	0	−4	− 1.6	− 6	+13	− 1	0	+ 7	− 3	+ 4	+ 3
05	0	−4	− 1.6	− 6	+10	− 3	− 2	+ 7	− 4	+ 3	+ 4
10	−1	−2	− 1.0	− 6	+ 8	− 3	− 2	+ 7	− 5	+ 1	+ 3
15	−1	−2	− 1.6	− 6	+ 7	− 4	− 3	+ 5	− 6	+ 1	+ 3
20	−1	−2	− 2.6	− 6	+ 7	− 2	− 3	+ 5	− 5	+ 2	+ 3
25	−2	−1	− 3.2	− 6	+ 6	− 1	− 2	+ 9	− 4	+ 2	+ 3
30	−2	+1	− 3.2	− 5	+ 7	− 1	− 1	+11	− 2	+ 2	+ 4
35	−1	0	− 3.2	− 5	+10	+ 1	− 1	+12	+ 2	+ 6	+ 5
40	−2	−1	− 4.2	− 6	+10	0	− 1	+ 9	+ 2	+ 4	+ 5
45	−4	−1	− 5.4	− 6	+ 8	− 4	− 2	+ 2	− 1	+ 3	+ 4
50	−6	−3	− 6.4	− 8	+ 5	− 6	− 4	− 2	− 3	0	+ 3
55	−6	−4	− 6.4	− 9	+ 2	− 6	− 7	− 5	− 9	− 4	+ 1
24 00	−7	−4	− 5.8	− 9	+ 1	− 6	− 6	− 3	− 6	− 4	+ 1
05	−8	−4	− 3.8	−10	0	− 5	− 6	+ 1	− 6	− 2	0
10	−8	−5	− 4.3	−10	− 1	− 4	− 7	+ 4	− 6	− 2	0
15	−9	−4	− 3.8	−10	0	− 6	− 6	+ 8	− 7	− 4	0
20	−8	−4	− 2.6	− 9	+ 1	− 1	− 5	+12	− 5	− 3	0
25	−9	−4	− 2.6	− 9	+ 5	− 4	− 4	+15	− 5	− 1	0
30	−8	−3	− 2.6	− 8	+ 7	− 2	− 3	+18	− 4	− 1	0
35	−9	−3	− 3.2	− 8	+ 6	− 3	− 3	+20	− 4	− 1	0
40	−8	−3	− 3.7	− 7	+ 5	− 1	− 2	+17	− 3	0	0
45	−8	−1	− 3.2	− 7	+ 2	− 4	− 2	+14	− 6	− 1	0
50	−7	−1	− 3.2	− 7	+ 2	− 6	− 1	+18	− 6	0	0
55	......	0	− 2.7	− 7	+ 3	−10	− 1	+17	− 4	+ 2	0
25 00	......	+1	− 1.6	− 4	+ 4	− 6	− 1	+16	− 1	+ 4	+ 1

Discussion of Vertical-Intensity Effects ($\triangle Z$-Curves).

62. Figure 14 exhibits graphically the vertical-intensity effects. The values of $\triangle Z$ were obtained by subtracting from the observed values of Z on June 8 the corresponding ones derived from the quiet days in June. For the observatories of the Coast and Geodetic Survey, Honolulu, Sitka, Tucson, Cheltenham, and Porto Rico, the data for the mean values of Z for 10 quiet days are given on page 120 of previous issue of *Terrestrial Magnetism;* for Agincourt and Meanook, the mean Z's for 5 quiet days are given in this issue, page 154. In the case of Kakioka, June 7 was taken as the undisturbed day (see this issue, page 151). The curves for Lukiapang and Antipolo are broken as the normal values of Z had to be deduced from published observatory values applying to previous years. The values of $\triangle Z$ are given in Table 19. *The curves are plotted so that a downward movement means an increase in the vertical intensity.* Attention should be called to the fact that the values of $\triangle Z$, as given in Table 19, do not necessarily represent absolute magnetic effects to be associated with the eclipse; they are affected, of course, by any constant or variable difference in Z between that of the mean normal day (taken as the mean of the quiet days) and that for June 8 had there been no eclipse. The absolute effect will be eliminated, more or less, in the differences of $\triangle Z$, as, for example, when getting the range in the $\triangle Z$-effect from a crest to a trough.

63. The first matter to be noticed is that directly after the beginning of the eclipse on the Earth, at $19^h\ 29^m$ as indicated by the dotted vertical line B in Fig. 14, there is a downward movement of the curves, meaning increasing Z, at Kakioka, Honolulu, Lakin, and Cheltenham. The time of occurrence of the trough, *a*, increases as we go eastward. At Agincourt there is at first a rise, or decrease of Z, which is then followed by a greatly delayed trough. At Tucson, south of the belt of totality, and at Porto Rico, outside the zone of visibility, there appears to be almost a continual decrease in Z throughout the entire interval of observation.

64. The *effect on the vertical intensity at Kakioka* during the time of the eclipse consists of a double wave as follows: About 20 minutes after the beginning of the eclipse we have a maximum Z, producing the trough *a*, which is then followed by a rise (*B*) in the curve or a minimum Z about 6 minutes after maximum obscuration; next, there is a trough *c* or a secondary maximum Z

TABLE 19.—*Five-minute values of △Z for June 8, 1918.*

G.M.T.	Ant.	Luk.	Kak.	Hon.	Sit.	Tuc.	Lak.	Agin.	Chel.	P. R.
h m	γ	γ	γ	γ	γ	γ	γ	γ	γ	γ
19 00	....	+3	— 9.9	+3	—24	+7	—27	+ 4	—8	+10
05	....	+3	—10.5	+2	—24	+7	—29	+ 4	—8	+10
10	....	+3	—10.6	+3	—24	+8	—28	+ 5	—8	+10
15	....	+3	—10.6	+4	—24	+8	—28	+ 6	—8	+11
20	....	+3	—10.6	+2	—23	+8	—27	+ 6	—7	+11
25	+5	+3	—10.0	+2	—23	+7	—26	+ 5	—8	+11
30	+5	+3	—10.0	+3	—22	+7	—26	+ 5	—7	+11
35	+5	+2	—10.6	+2	—21	+7	—25	+ 4	—6	+10
40	+7	+2	—10.6	+3	—21	+6	—24	+ 4	—6	+10
45	+5	+2	— 9.3	+4	—21	+6	—25	+ 4	—5	+10
50	+6	+3	— 8.6	+4	—21	+6	—25	+ 3	—5	+10
55	+5	+3	— 8.6	+5	—21	+6	—22	+ 3	—6	+10
20 00	+5	+3	— 8.7	+5	—21	+5	—21	+ 4	—5	+10
05	+4	+4	— 8.1	+6	—21	+5	—17	+ 4	—5	+ 9
10	+4	+4	— 8.1	+6	—22	+5	—18	+ 4	—6	+ 8
15	+4	+4	— 8.7	+7	—22	+5	—17	+ 5	—5	+ 8
20	+2	+4	— 9.3	+6	—22	+4	—16	+ 5	—5	+ 8
25	+2	+4	— 9.9	+6	—21	+4	—14	+ 4	—5	+ 8
30	+2	+4	—10.6	+5	—18	+4	—15	+ 5	—5	+ 8
35	+4	+4	—11.8	+5	—20	+5	—15	+ 5	—5	+ 8
40	+4	+4	—12.4	+5	—20	+4	—15	+ 5	—5	+ 9
45	+2	+3	—13.1	+5	—20	+5	—15	+ 4	—4	+10
50	+2	+3	—13.1	+5	—20	+5	—13	+ 4	—4	+ 9
55	+2	+3	—10.5	+5	—20	+5	—15	+ 4	—4	+ 9
21 00	+2	+3	—10.5	+3	—23	+5	—16	+ 5	—3	+ 9
05	+1	+3	— 9.3	+3	—23	+5	—17	+ 7	—1	+ 6
10	0	+4	— 9.9	+3	—24	+5	—20	+ 7	0	+ 5
15	+1	+3	— 9.9	+2	—20	+4	—20	+ 6	—1	+ 4
20	+2	+3	—10.6	+2	—19	+4	—21	+ 6	—1	+ 5
25	+2	+2	—11.1	0	—20	+4	—22	+ 6	—1	+ 5
30	+3	+2	—11.1	0	—20	+4	—20	+ 6	—1	+ 5
35	+2	+2	—11.1	—1	—20	+4	—19	+ 7	—2	+ 5
40	+2	+2	—10.5	—1	—21	+4	—22	+ 8	—1	+ 5
45	+2	+2	— 9.8	—1	—21	+4	—20	+ 9	—1	+ 5
50	+2	+1	—11.1	—1	—22	+4	—21	+ 9	—1	+ 5
55	+1	0	—11.1	—1	—23	+5	—21	+11	0	+ 6
22 00	0	0	—10.5	—1	—23	+5	—22	+11	0	+ 7
05	+1	0	— 9.9	—2	—24	+4	—22	+11	+1	+ 6
10	—1	+1	— 9.9	—2	—24	+4	—22	+11	+1	+ 6
15	—2	+1	—10.5	—2	—24	+4	—22	+11	+1	+ 6
20	—2	0	—11.1	—1	—24	+4	—23	+11	+1	+ 5
25	—2	—1	—12.9	—1	—23	+4	—22	+10	+1	+ 5
30	—2	—1	—13.5	0	—24	+4	—24	+11	0	+ 6
35	—3	0	—14.8	+1	—23	+5	—25	+10	0	+ 6
40	—5	—1	—16.0	+1	—22	+4	—27	+10	0	+ 7
45	—5	—1	—16.6	0	—22	+4	—29	+10	—1	+ 7
50	—6	—2	—17.2	0	—22	+4	—29	+10	—1	+ 7
55	—7	—3	—16.6	0	—23	+4	—29	+10	—3	+ 6
23 00	—8	—3	—16.6	—1	—24	+3	—28	+10	—3	+ 6
05	—8	—3	—15.4	0	—26	+3	—28	+10	—2	+ 6
10	—7	—4	—15.4	0	—26	+3	—26	+10	—3	+ 6
15	—8	—5	—15.4	0	—26	+3	—27	+ 9	—3	+ 6
20	—7	—5	—15.4	—1	—26	+3	—28	+10	—4	+ 6
25	—7	—5	—14.8	0	—27	+3	—27	+11	—4	+ 6
30	—6	—5	—14.1	+1	—27	+3	—26	+11	—4	+ 6
35	—6	—6	—14.1	+1	—26	+3	—27	+11	—4	+ 6
40	—5	—6	—13.5	+1	—27	+3	—28	+11	—5	+ 6
45	—6	—5	—12.9	+1	—27	+3	—28	+10	—4	+ 6
50	—5	—5	—12.3	+1	—28	+3	—30	+ 9	—4	+ 5
55	—5	—5	—11.1	+1	—29	+3	—30	+ 8	—6	+ 5
24 00	—4	—4	—10.5	+1	—30	+2	—31	+ 9	—5	+ 5
05	—4	—5	—11.0	+1	—29	+3	—31	+ 9	—4	+ 5
10	—3	—5	—13.6	+1	—30	+3	—31	+ 9	—4	+ 4
15	—3	—5	—14.2	+1	—30	+4	—32	+ 9	—5	+ 4
20	—3	—5	—15.4	+1	—30	+3	—33	+ 8	—5	+ 3
25	—2	—6	—16.0	+1	—29	+4	—31	+ 9	—5	+ 3
30	—1	—5	—17.2	+1	—28	+4	—27	+10	—5	+ 3
35	—3	—6	—18.4	+1	—28	+4	—28	+10	—5	+ 3
40	—2	—5	—19.7	+1	—28	+4	—27	+10	—5	+ 2
45	0	—5	—20.4	+1	—29	+4	—28	+10	—6	+ 2
50	+1	—5	—20.3	+1	—30	+4	—27	+10	—6	+ 3
55	....	—5	—20.3	+1	—29	+4	—27	+10	—6	+ 2
25 00	....	—4	—20.3	+1	—29	+4	—26	+10	—6	+ 2

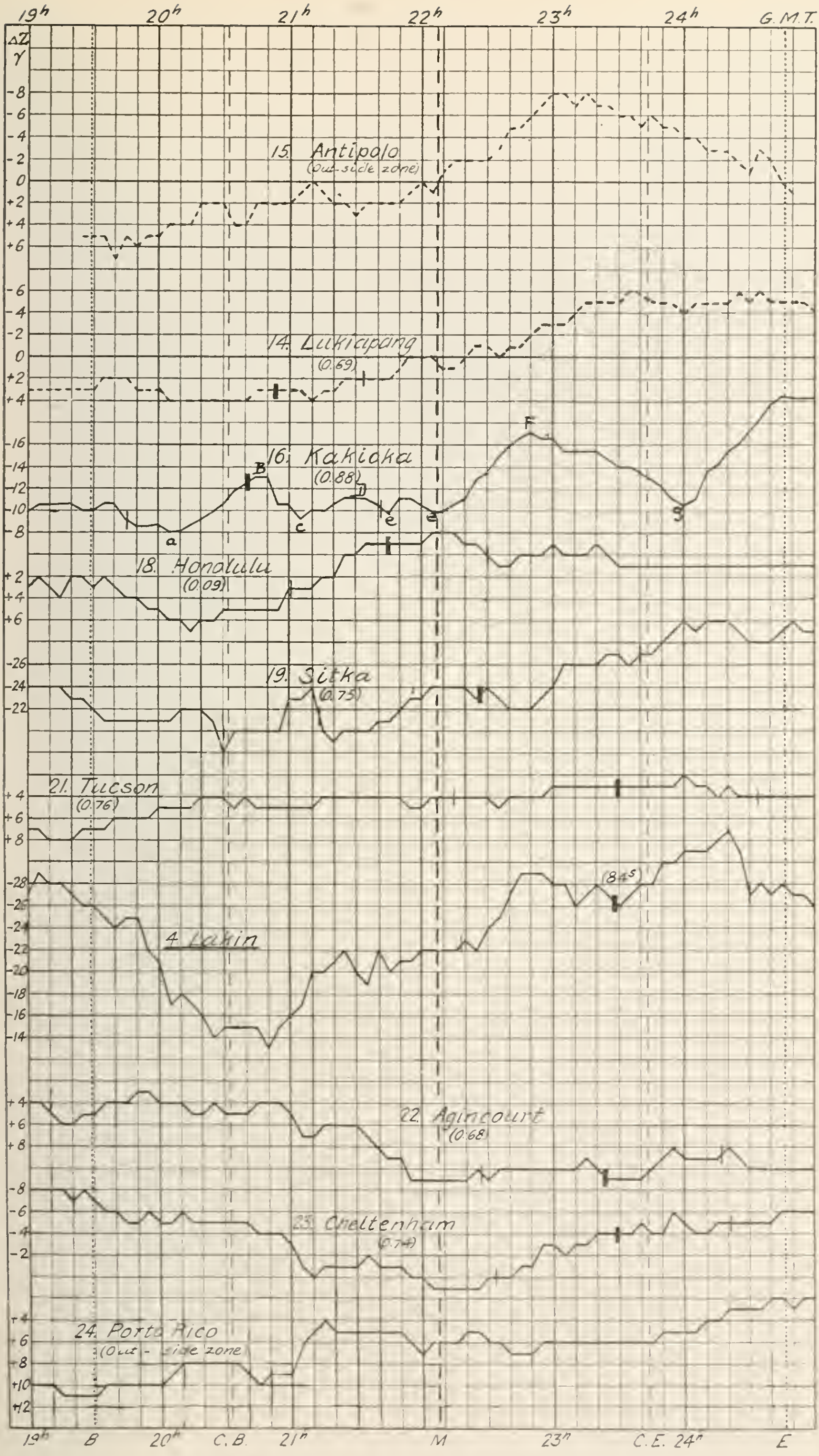

FIG. 14.—Δ Z-Curves, Solar Eclipse, June 8, 1918.

about 23 minutes after maximum obscuration, and then a crest (D) or secondary minimum Z, about 12 minutes before the end of the eclipse.

65. The *effects at the succeeding stations* during the period of the eclipse are more or less modified, according to location of station and preliminary effects. In general there is a tendency to the formation of a crest, or a minimum Z, shortly before or after the time of maximum obscuration. At Lakin and Cheltenham there is seemingly a trough (increased Z) near maximum obscuration. Only at Lakin was the eclipse total; the curve at this station shows, apparently, the greatest range, viz., from -13γ at $20^h\ 50^m$ to -33γ at $24^h\ 20^m$, or $20\gamma = 0.037$ per cent of Z; however, there is some uncertainty as to the scale value, which, of course, would affect the range. At Kakioka, where the maximum obscuration is 0.88 we have the next largest range, viz., from -8.1γ at $20^h\ 07^m.5$ to -20.4γ at $24^h\ 45^m$, or $12.3\gamma = 0.035$ per cent of Z. Other things being equal, the range may possibly be proportional to the magnitude of obscuration. Confining attention alone to the Kakioka and Lakin curves, it would seem that approximately at the same absolute time the chief effects are sometimes opposite in character. Table 25 contains the characteristic features for the $\triangle Z$-curves.

First Chief Conclusion.

The first chief conclusion to be drawn from the results thus far obtained from the magnetic observations made in connection with the solar eclipse of June 8, 1918, is as follows:

Appreciable magnetic effects were observed during the solar eclipse of June 8, 1918, at stations distributed over the entire zone of visibility and immediately outside. (How much further some of the effects may have extended must be left for future study.) The chief characteristics of the effects took place generally in accordance with the local eclipse circumstances and in general accord with effects observed during previous eclipses. The evidences of a direct relation between the magnetic effects and the solar eclipse are so numerous as to warrant drawing the definite conclusion that an appreciable variation in the Earth's magnetic field occurs during a solar eclipse. This particular variation is termed here the "solar-eclipse magnetic variation."

Further evidences will be found in the subsequent paragraphs.

(*To be continued.*)

LATEST ANNUAL VALUES OF THE MAGNETIC ELEMENTS AT OBSERVATORIES.[1]

COMPILED BY J. A. FLEMING.

Observatory	Latitude	Longitude	Year	Declination (D)	Inclination (I)	Intensity Hor. (H)	Intensity Ver. (Z)
	° ′	° ′		° ′	° ′	c. g. s.	c. g. s.
Sitka	57 03 N	135 20W	1916[2]	30 23.9 E	74 25.6 N	.15585	.55923
			1917	30 25.0 E	74 25.1 N	.15579	.55867
Rude Skov	55 51 N	12 27 E	1916	8 34.6W	68 52.7 N	.17229	.44599
Eskdalemuir	55 19 N	3 12W	1914	17 45.3W	69 36.1 N	.16804	.45188
Meanook	54 37 N	113 20W	1916[3]	27 48.6 E	77 55.9 N	......	......
			1917	27 46.4 E	77 55.0 N	.12941[4]	......
Stonyhurst	53 51 N	2 28W	1916	16 25.6W[5]	68 41.9 N	.17346[5]	.44483
			1917	16 16.4W[5]	68 42.0 N	.17340[5]	.44475
Potsdam[6]	52 23 N	13 04 E	1917	7 58.4W	66 29.3 N	.18671	.42916
Seddin[6]	52 17 N	13 01 E	1917	7 59.7W	66 26.3 N	.18709	.42901
Valencia[7]	51 56 N	10 15W	1914	20 12.3W	68 07.8 N	.17895	.44585
Greenwich	51 28 N	0 00	1917	14 37.0W	66 53.6 N[8]	.18477	.43305
Val Joyeux	48 49 N	2 01 E	1914	13 49.8W	64 37.7 N	.19733	.41609
Agincourt	43 47 N	79 16W	1917	6 36.2W	74 44.2 N	.15950	.58449
Capodimonte[9]	40 52 N	14 15 E	1907	8 34.8W	56 13.1 N	.24146	.36094[10]
			1908	8 28.3W	56 13.0 N	.24153	.36102[10]
			1909	8 21.3W	56 14.4 N	.24129	.36098[10]
			1910	8 13.0W	56 11.9 N	......	......
			1911	8 05.5W	56 11.7 N	.24171	.36099[10]
Coimbra	40 12 N	8 25W	1916	15 50.1W	58 32.2 N	.23046	.37662
Cheltenham	38 44 N	76 50W	1916[11]	6 07.7W	70 49.6 N	.19341	.55624
			1917	6 10.3W	70 51.8 N	.19269	.55531

[1]See tables for previous years in *Terr. Mag.*, vol. 4, p. 135; vol. 5, p. 128; vol. 8, p. 7; vol. 12, p. 175; vol. 16, p. 209; vol. 20, p. 131, and vol. 22, p. 169.

[2]Final values to replace the preliminary ones published in vol. 22, p. 169; the values for 1917 are preliminary ones.

[3]Observations during September to December only.

[4]Mean of two observations monthly during October to December only.

[5]From magnetograms for the ten least disturbed days in each month.

[6]Preliminary values transmitted by Prof. E. van Everdingen.

[7]Means of two absolute observations monthly.

Observatory	Latitude	Longitude	Year	Declination (D)	Inclination (I)	Intensity Hor. (H)	Intensity Ver. (Z)
	° ′	° ′		° ′	° ′	c. g. s.	c. g. s.
Kakioka[12]....	36 14 N	140 11 E	1913	5 10.1W	49 30.9N[13]	.29749	.34851
Tucson......	32 15 N	110 50W	1917	13 46.1 E	59 26.4N	.27021	.45763
Lukiapang[14]..	31 19 N	121 02 E	1908[15]	2 57.3W	45 35.1 N	.33196	.33882
			1909	2 58.6W	45 34.9 N	.33207	.33887
			1910	3 01.1W	45 34.4 N	.33217	.33888
			1911	3 02.5W	45 33.9 N	.33225	.33887
			1912[15]	3 04.6W	45 32.9 N	.33228	.33870
			1913	3 07.2W	45 32.6 N	.33233	.33870
Dehra Dun[16].	30 19 N	78 03 E	1915	2 15.5 E	44 30.6 N	.33083	.32522
Hongkong[17]..	22 18 N	114 10 E	1917	0 16.3W	30 50.4 N	.37163	.22188
Honolulu....	21 19 N	158 04W	1916[18]	9 43.9 E	39 28.5 N	.28966	.23856
			1917	9 46.3 E	39 27.2 N	.28935	.23812
Toungoo[19]....	18 56 N	96 27 E	1915	0 03.1W	23 07.2 N	.39005	.16653
Vieques.....	18 09 N	65 26W	1916	3 19.2W	50 55.5 N	.28158	.34680
			1917	3 26.9W	51 04.1 N	.28057	.34732
Antipolo[20]....	14 36 N	121 10 E	1911	0 41.3 E	16 18.6 N	.38072	.11140
Kodaikanal[21].	10 14 N	77 28 E	1915	1 22.3W	4 17.0 N	.37614	.02817
Tananarivo[22]	18 55S	47 32 E	1909	9 13.0W	53 59.8S	.22692	.31229
			1910	9 01.3W	53 58.9S	.22585	.31065
			1911	8 48.6W	53 53.5S	.22571	.30943
			1912	8 38.9W	53 46.2S	.22503	.30713
			1913	8 31.4W	53 39.0S	.22492	.30563
			1914	8 25.2W	53 37.9S	.22484	.30532
Mauritius....	20 06S	57 33 E	1916	9 47.6W	52 54.6S	.23201	.30688
Pilar[23].......	31 40S	63 53W	1905	9 51.7 E	26 03.0S	.25894	.12657
			1906	9 45.0 E	26 01.0S	.25850	.12617
			1907	9 38.1 E	26 00.7S	.25805	.12592
			1908	9 29.1 E	25 57.3S	.25787	.12552
			1909	9 21.6 E	25 55.7S	.25746	.12518
			1910	9 13.9 E	25 52.8S	.25694	.12465
			1911	9 05.4 E	25 49.4S	.25681	.12428
			1912	8 57.1 E	25 45.5S	.25666	.12384
			1913	8 49.0 E	25 43.7S	.25635	.12353

[8]Mean from earth-inductor observations.

[9]The declination values for 1905 and 1906 published in *Terr. Mag.*, vol. 20, p. 133, should read *West* instead of East.

[10]Computed from *I* and *H*.

[11]Final values to replace preliminary ones published in vol. 22, p. 170; the values for 1917 are preliminary ones.

[12]This observatory succeeded Tokio Observatory in January 1913 because of electric tramway disturbances at Tokio. In 1916 it was found "that absolute values at Tokio were approximately obtained from those at Kakioka by adding the following corrections: —5′.5 for declination, 0.00265 c. g. s. for horizontal intensity, and 0.00481 c. g. s. for vertical intensity."

Observatory	Latitude	Longitude	Year	Declination (*D*)	Inclination (*I*)	Intensity Hor. (*H*)	Intensity Ver. (*Z*)
	° ′	° ′		° ′	° ′	c. g. s.	c. g. s.
Melbourne...	37 50S	144 58 E	1916	8 06.7 E	67 48.9N	.22998	.56397[24]
			1917	8 03.2 E	67 50.9N	.22961	.56400[24]
Christchurch.	43 32S	172 37 E	1913	16 42.0 E	67 58.2S	.22448	.55478
			1914	16 44.8 E	67 59.8S	.22413	.55465
			1915	16 47.0 E	....	.22387	....
			1916	16 49.8 E	....	.22355	....
New Year's Island.....	54 39S[25]	64 09W[25]	1907	15 38.1 E	50 01.7S[26]	.27135	.32370
			1908	15 34.1 E	49 58.8S	.27105	.32279
			1909	15 30.3 E	49 56.3S	.27065	.32185
			1910	15 26.3 E	....	.27040	.32114[27]
			1911	15 22.0 E	....	.26996	.31984[28]
			1912	15 18.1 E	49 48.1S	.26963	.31908
			1913	15 14.3 E	49 45.8S	.26924	.31819
			1914	15 10.3 E	49 43.4S	.26878	.31719
			1915	15 06.6 E	49 41.6S	.26821	.31619
			1916	15 02.4 E	49 39.4S	.26771	.31520

[13]Computed from *H* and *Z*.

[14]The values given are without the approximate reductions to Carnegie Institution of Washington Magnetic Standards (see *Researches of the Department of Terrestrial Magnetism*, vol. 2, p. 270 *et seq.*) as applied in the data given in previous tables.

[15]The values for 1908 are for September to December only; those for 1912 are for January to August and November to December only.

[16]The values of *H* and *Z* are on the basis of new value for the moment of inertia and revised values of the distribution coefficients; the values of *H* and *Z* for 1914 if based on the new constants would have been 0.33134 and 0.32427 c. g. s., respectively.

[17]The intensity values are based on *P*, the distribution coefficient, equal 7.05 instead of the year's mean value; had the average annual values of *P* been used the corrections to published values of *H* for the years 1912 to 1917 would be +0.00013, —0.00007, —0.00008, —0.00001, —0.00011, and —0.00009 c. g. s., respectively.

[18]Final values to replace the preliminary ones published in vol. 22, p. 171; the 1917 values for Vieques are preliminary ones.

[19]The values of *H* and *Z* are on the basis of new values for the moment of inertia and revised values of the distribution coefficients; the values of *H* and *Z* for 1914 would have been 0.38965 and 0.16621 c. g. s., respectively.

[20]Revised values referred to Carnegie Institution of Washington Magnetic Standards (see footnote 14) by the following corrections: *D*, +1′.9; *H*, —0.00199*H*; *I*, +0′.1.

[21]The values of *H* and *Z* are on the basis of new value for the moment of inertia and revised values of the distribution coefficients; the values of *H* and *Z* for 1914 if based on the new constants would have been 0.37604 and 0.02753 c. g. s., respectively.

[22]The values are as given by Dr. C. Chree in *British Meteorological and Magnetic Year Book* for 1914; the intensity values previously published in *Terr. Mag.*, vols. 12, 16, and 20, are means of values published in *Comptes Rendus* but may be in error.

[23]Corrected values.

[24]Computed from *I* and *H*.

[25]Supersedes provisional value published in vol. 22, p. 172.

[26]Values for *I* computed from *H* and *Z*.

[27]January to September only.

[28]April and August to December only.

Table Showing the Magnetic Character of the Year 1917.

Dates	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	Mean
January	0.8	0.5	0.1	2.0	1.6	1.2	1.0	1.0	0.8	0.9	0.8	1.3	1.1	0.5	0.1	0.5	0.5	0.3	0.7	1.0	1.1	1.3	1.1	0.7	1.1	0.9	0.7	0.1	0.3	0.5	0.8	0.81
February	0.1	0.4	0.2	0.5	0.7	0.7	0.9	0.8	0.1	0.4	0.5	0.0	0.2	0.6	1.9	1.5	0.7	1.1	1.1	1.5	0.8	0.9	0.8	0.7	0.6	0.7	0.4	0.7				0.69
March	0.7	0.1	0.3	1.1	1.5	1.0	0.8	1.3	0.7	0.5	0.3	0.4	1.0	0.2	0.8	0.8	0.1	0.2	0.2	1.0	1.0	0.7	0.6	0.4	1.1	0.4	0.8	0.0	0.1	0.0	0.4	0.59
April	0.6	0.9	1.0	0.6	1.0	1.2	0.6	0.8	1.4	0.1	0.0	0.3	0.3	0.0	0.8	1.2	0.9	0.9	0.1	0.1	0.2	0.7	0.5	0.7	0.9	1.4	0.1	0.1	0.5	1.0		0.63
May	1.2	1.5	1.4	0.9	0.9	0.1	0.4	0.0	0.6	0.3	0.3	0.3	0.2	0.9	0.3	1.2	0.8	0.5	0.1	0.2	0.7	0.8	0.6	0.4	0.7	0.7	1.0	1.3	1.1	0.8	0.3	0.66
June	0.0	0.0	0.7	1.0	0.0	0.5	1.5	1.0	0.6	0.5	0.3	0.2	1.2	0.9	0.4	0.5	0.4	0.1	0.0	0.0	0.0	0.8	1.3	1.7	1.2	0.5	0.1	0.4	0.4	0.1		0.55
July	0.2	1.3	1.1	0.5	0.1	0.1	0.8	0.2	0.1	0.5	1.0	0.8	1.5	0.6	0.3	0.0	0.0	0.0	0.2	0.0	1.1	1.2	0.2	0.3	0.3	0.2	1.0	1.1	1.5	0.9	1.8	0.61
August	1.1	0.3	0.3	0.1	0.1	0.0	0.8	0.7	2.0	1.7	0.6	0.4	1.9	1.9	1.6	0.9	0.6	0.4	0.1	1.2	1.9	1.4	1.4	0.5	1.0	1.7	0.5	0.1	0.1	0.7	0.2	0.85
September	0.1	1.1	1.1	0.9	1.7	0.7	0.3	0.5	1.1	0.3	0.1	0.3	0.4	0.2	0.3	0.3	0.5	0.8	1.1	1.0	0.8	0.7	0.0	0.5	0.2	0.1	0.3	0.8	0.8	1.1		0.61
October	1.0	1.2	1.3	1.1	0.9	0.9	0.3	1.0	0.7	0.4	1.0	0.2	1.4	1.6	0.4	0.1	0.3	0.1	0.1	0.1	0.0	0.1	0.7	0.8	1.3	0.1	0.4	1.6	1.6	1.2	1.0	0.74
November	0.7	0.2	0.2	0.0	0.1	0.4	0.3	0.3	0.1	0.1	0.4	1.6	1.0	1.3	0.1	0.1	0.3	0.4	1.0	0.8	0.1	0.3	0.0	0.4	1.2	1.4	1.4	0.9	0.5	0.2		0.53
December	0.4	0.9	1.1	1.1	0.9	0.5	0.7	1.2	0.8	0.1	0.6	0.5	0.1	0.9	0.4	2.0	1.6	1.6	1.1	1.0	0.4	0.0	0.3	0.3	0.7	1.2	0.5	0.2	0.5	0.5	0.1	0.72

Calm Days.

January	3,	15,	18,	28,	29	February	1,	9,	12,	13,	27	March	2,	3,	28,	29,	30
April	10,	11,	14,	20,	27	May	6,	8,	13,	19,	20	June	1,	2,	19,	20,	30
July	6,	16,	17,	18,	20	August	5,	6,	19,	28,	29	September	1,	11,	23,	25,	26
October	16,	19,	20,	21,	22	November	9,	10,	15,	16,	23	December	10,	13,	22,	23,	31

Days Recommended for Reproduction.

**January 4; June 24; August 9, 13 and 14; December 16.

*February 15; April 26; July 31; August 21; September 5; October 14 and 29; November 12; December 18.

THE MAGNETIC CHARACTER FOR THE YEAR 1917.

BY G. VAN DIJK.

The annual review of the "Caractère magnétique de chaque jour" for 1917 has been drawn up in the same manner as for the years 1906-1915; 39 observatories contributed to the quarterly reviews, 35 of them sending complete data. The table on page 194 contains the mean character of each day and each month, the list of "calm days" and the days recommended for reproduction.

MOST MAGNETICALLY-DISTURBED DAYS IN 1917.

BY E. VAN EVERDINGEN.

According to the De Bilt circular, December 1917, the following is a list of the most magnetically-disturbed days in 1917:

January	4	5	12	22	23
February	15	16	18	19	20
March	4	5	8	21	25
April	5	6	9	16	26
May	1	2	3	16	28
June	7	13	23	24	25
July	2	13	22	29	31
August	9	10	13	14	21
September	2	5	9	19	30
October	3	13	14	28	29
November	12	14	25	26	27
December	8	16	17	18	26

ABSTRACTS AND REVIEWS

STRONG, W. W.: *The New Science of the Fundamental Physics.*[1]

The new science is characterized by the author as "a more complete application of laboratory methods to the basic units, measurements and laws of science. It aims to apply the empirical methods and eventually the same method, units and apparatus to all phenomena. . . . It states that no terms or theory of the natural world possesses any meaning unless it is usable in the laboratory. Such terms as time, length, direction and mass must be definable in terms of experiences of the natural world and unless they can be so defined

[1]Mechanicsburg, Pa., 1918, pp. xi+107, 23 cm.

in a given region of experience they possess no meaning there, fundamental though these terms may appear to be."

The origin of the new science is attributed to the discovery of the non-Euclidean geometries, the electron, radioactivity, the propagation of light with reference to the Earth's motion, and other radiation phenomena.

Nineteen brief chapters are devoted to the discussion of the conservation of energy, mass, and electric charge; ionization; the growth of science as related to the human perceptive powers; the procedure of the new science; the "directional elements" and the individuals, or "entity systems," of the universe; atomic structure, equipartition of energy, and radioactivity; models of atoms and atomic nuclei; the corpuscular theory and the wave theory of light; electric lines of force; the equipartition of energy and the electromagnetic theory of radiation and gravitation; the electric nature of the ether, and "electroethons" and "radions"; universal constants, and units and definitions of fundamental quantities; and the quantum theory and theory of relativity.

The work is written from the standpoint of an ardent and reverent student of nature. As would be expected from the author's scientific standing, his statements with regard to scientific facts and theories are almost always accurate. An exception occurs in the description of the Thomson atom, in which the force on an electron is said to be "indirectly proportional to the square of the distance of the electron from the center," instead of proportional to this distance. The author's own contributions are instructive and interesting. The style is not entirely free from obscurity and other blemishes. The treatment of modern developments would be of greater service to those not already acquainted with the subject if it were not so brief· and the brief treatment given would be more serviceable if accompanying references to original sources of information were not so scarce. S. J. Barnett.

Department of Terrestrial Magnetism.

A PRACTICAL MANUAL OF THE COMPASS.[1]

This publication is a compilation from various sources, and is intended for practical instruction in the use of liquid- or gyro-compasses at sea. Ship deviations are explained in a popular style without reference to elaborate mathematical theory.

Six chapters out of the total thirteen are devoted to the compensation of compasses, in which, principles are explained and the various steps and methods are minutely given. These chapters alone make the book invaluable to the practical compass-adjuster.

There are notes on the U. S. Navy regulations regarding the compass, examples of forms and descriptions of compasses used in the U. S. Navy, together with their accessories. Two chapters are written on the gyro-compass in general, in which the Sperry gyro-compass is described quite sufficiently for practical purposes.

The utility of the publication will be most appreciated by the navigator who is not familiar with, or has little time for mathematics.

Department of Terrestrial Magnetism. W. J. Peters.

[1]Annapolis, Md., U. S. Naval Institute, 1916, 146 pp., 26 cm.

RECENT PUBLICATIONS

A. Terrestrial and Cosmical Magnetism.

AGINCOURT AND MEANOOK OBSERVATORIES. Magnetic observations. May, June, July, and August, 1918. Toronto, J. R. Astr. Soc. Can., v. 12, (370-371), (413-415), (466-467), 1918.

ARGENTINA. MINISTERIO DE MARINA. Anales hidrográficos. Tomo II. Buenos Aires, Ministerio de Marina, Secretaria General, División de Hidrografía, Faros y Balizas, 1918 (463 con figs.). 25 cm. [Contains values of the monthly and annual means of magnetic elements at Isla de Año Nuevo Observatory from the year 1907 to 1916 inclusive, as also values obtained at certain field stations in 1916.]

BAUER, L. A. Corresponding changes in the Earth's magnetic state and in solar activity, 1888-1916. Abstr. J. Wash. Acad. Sci., Washington, D. C., v. 8, No. 14, Aug. 19, 1918 (506-507). [Paper presented to Philosophical Society of Washington, May 11, 1918.]

BIRKELAND, KR. Obituary of Professor Kr. Birkeland. Cairo Sci. J., Alexandria, v. 9, No. 101, April, May and June, 1917 (33).

BUREAU DES LONGITUDES. Annuaire pour l'an 1918. Avec des notices scientifiques. Paris, Gauthier-Villars et C^{ie} (676+A.42+B.45+C.22+D.21+E.63). 15½ cm. [Contains magnetic charts of France for the epoch January 1, 1911, and tables of the values of the magnetic elements at various stations in France, Tunis, Algeria and Morocco for the epoch January 1, 1911, as also an article on "Le Soleil et le magnétisme terrestre" by M. Hamy.]

CHREE, C. Terrestrial magnetism in relation to mine surveying. Repr. London, Trans. Inst. Min. Engin., v. 55, Pt. 4, 1918 (223-263).

CHREE, C. The magnetic storm of December 16-17, as recorded at Kew and Eskdalemuir Observatories. London, Proc. R. Soc., A, v. 94, 1918 (525-547).

COIMBRA. Observações meteorológicas, magnéticas e sísmicas feitas no Observatório Meteorológico de Coimbra no ano de 1916. Volume LV. Coimbra, Imprensa da Universidade, 1917 (viii+165). 36 cm.

COPENHAGEN, DET DANSKE METEOROLOGISKE INSTITUT. Magnetisk Aarbog. Annuaire magnétique. 1916. Kjøbenhavn, G. E. C. Gad, 1918 (11 avec 16 pls.). 32 cm. [French text.]

ESPOSITO, M. Notes on the early history of the mariner's compass. London, Geog. J., v. 52, No. 5, Nov., 1918 (308-311).

GREENWICH. The Royal Observatory, Greenwich. Nature, London, v. 101, No. 2536, June 6, 1918 (278). [The mean values of the magnetic elements for 1914-1917 are given.]

HABANA. Observatorio Meteorológico, Magnético y Seismico del Colegio de Belén de la Compañía de Jesus en la Habana. Año de 1917. Habana, Imprenta y Papelería La Universal, Junio, 1918, ca. 80 pp. 36 cm. [Contains no magnetic observations.]

HONGKONG, ROYAL OBSERVATORY. Report of the Director of the Royal Observatory, Hongkong, for the year 1917. (T. F. Claxton, Director.) Hongking, Noronha & Co., Govt. Printers, 1918, 14 pp. 24 cm.

KEW OBSERVATORY. The variation of the magnetic compass from true north. London, Q. J. R. Meteor. Soc., v. 44, No. 187, July, 1918 (221-222). [Note regarding publication of weekly tables of mean magnetic declination at Kew Observatory for the use of mine surveyors.]

MERCANTON, P.-L. État magnétique de terres cuites préhistoriques. Lausanne, Bul. Soc. Sci. Nat., v. 52, No. 194, 1918 (9-15).

NODON, A. Relations entre les variations électromagnétiques terrestres et l'état de l'atmosphère. Paris, Bul. soc. astr. France, 32 année, août 1918 (289-290).

NODON, A. Orage électromagnétique. Paris, C.-R. Acad. sci., T. 167, No. 19, 4 novembre 1918 (688-689).

SCHMIDT, AD. Erdmagnetismus. (Sonderabdruck aus Encyklopädie d. mathematischen Wissenschaften. VI 1, B, pp. 266-390.) Leipzig, B. G. Teubner, 1917.

SIAM. Report on the operations of the Royal Survey Department of the Army for the year 1916-1917. Bangkok, Bangkok Daily Mail Press, 1918 (42 with map). 33 cm. [Contains results of magnetic observations 1905-1917.]

ZI-KA-WEI, OBSERVATOIRE DE. Observations magnétiques faites à l'Observatoire de Lu-kia-pang. Tome VI. Année 1913. Zi-ka-wei—Chang-hai, Imprimerie de la Mission Catholique, 1918 (79 avec 7 pl. et 3 diagrammes). 31 cm.

B. *Terrestrial Electricity and Radioactivity.*

DECHEVRENS, M. Une marée électrique dans le sol, dérivée de la marée océanique. (Observations faites d'octobre 1917 à août 1918 à l'observatoire Saint-Louis, à Jersey.) Paris, C.-R. Acad. sci., T. 167, No. 16, 14 octobre 1918 (552-555). [See *Terr. Mag.*, vol. 23, p. 145, 1918.]

JONES, H. S. The corpuscular theory of the Aurora Borealis. Observatory, London, v. 41, No. 523, Feb., 1918 (92-94).

LESTER, O. C. The radioactive properties of the natural springs of Colorado. Amer. J. Sci., New Haven, Conn., v. 46, No. 275, Nov., 1918 (621-637).

SIMPSON, G. C. Auroral observations in the Antarctic. Nature, London, v. 102, No. 2550, Sept. 12, 1918 (24-25). [A brief comment by C. Chree is added.]

STÖRMER, C. La théorie corpusculaire des aurores boréales. Paris, Bul. soc. astr. France, v. 32, May, 1918 (153-159); June, 1918 (200-205).